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The Separation of Isotopes—A Survey

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SOON after the discovery of radioactivity, chemists were able to show that some of the new radioactive substances could not be separated from other, nonradioactive substances, by any known chemical means. Now, radioactivity was found to be a property of the nucleus, whereas the chemical combining properties of an atom were known to be determined by the extranuclear electrons. Hence it was concluded that, in the case of these heavy elements, at least, atoms could exist having the same extranuclear structure but with different nuclear compositions. Such different constituents of the same chemical element were given the name *isotopes* (Gr., "equal place"), because, since they have the same number of extranuclear electrons, they must carry the same nuclear charge and consequently have the same atomic number; that is, they occupy the same place in the periodic table of the elements.

In 1919 the existence of two isotopic constituents of neon was established by F. W. Aston. This discovery made it seem reasonable to expect that many elements, besides the radioactive ones, might be composed of isotopes, and opened up a whole new field of investigation. In the subsequent twenty years, mass-spectrographic analysis has revealed the existence in nature of more than 200 stable isotopes of the various elements, while nuclear disintegration experiments have succeeded in producing, in addition to this number, about 200 unstable or radioactive isotopes. Thus, in order to specify completely an atom, it is necessary to give both its *atomic number* (or the name of the element) and another number that indicates to which of the various isotopes of that element the atom in question belongs. Now it turns out that the mass of any atom is very nearly a whole number, on a scale which assigns to the least massive (and most common) atom of oxygen the value 16.000000. Consequently one speaks of the isotopes H^1 and H^2 of hydrogen, C^{12} and C^{13} of carbon, etc.—meaning an atom (or atoms) of hydrogen of approximate mass 1 or 2, an atom of carbon of approximate mass 12 or 13, etc.

Now, when one learns that an element, in general, is not made up of identical atoms, but consists of a mixture of atoms of different masses, he immediately wonders how it is that the chemists did not discover this as soon as they began measuring atomic weights. We say, for example, that the atomic weight of chlorine is 35.46. In the light of our present knowledge, we interpret this as meaning that, in the sample of chlorine upon which the atomic weight determination was made, atoms of the isotopes Cl^{35} and Cl^{37} were mixed together in such proportions that their *average* mass was 35.46. But if the measurement were to be repeated on a sample of chlorine collected in some other region of the earth, or under entirely different circumstances, we might expect the resulting atomic weight to be appreciably different. Conversely, if such variations in the atomic weight of chlorine had been discovered, the existence of its isotopes would have

been established long before the advent of the mass spectrograph. But such variations are not observed. Whether the chlorine comes from the sea, from rocks, or even from meteorites, the atomic weight is always the same, within experimental error. With the single exception of lead, whose atomic weight depends on whether or not it has been produced by the radioactive disintegration of heavier substances, all evidence indicates that nature has, in the far distant past, mixed together the various kinds of atoms of each particular element in proportions which no subsequent natural process seems able to alter appreciably.[1]

This invariance of isotopic proportions constitutes a limitation on certain physical and chemical experiments. In the field of mass spectrography, for instance, it would be easier to detect the existence of a rare isotope if it were possible to find a material in which this isotope is relatively highly concentrated. Then again, when the nuclear physicist bombards a target with high speed particles and observes other particles ejected from the target, the problem of identifying the particular nuclear reaction which he has produced would be simplified if the reaction could be definitely assigned to a particular isotope of the target material, and this in turn would be possible if targets of different isotopic compositions could be made. The spectroscopist, too, would like to have at his disposal elements of various isotopic compositions, for there are types of spectral lines that are characteristic of the mass of the atoms involved in their production. Moreover, several kinds of interesting chemical information could be acquired if there were available quantities of elements of different isotopic proportions; for example, the rate of interchange of hydrogen between two hydrogen-containing substances in a mixture could be investigated by synthesizing the two substances from quantities of hydrogen having different mixing ratios of the isotopes H^1 and H^2, and observing how the isotopic composition of each substance changes with time.

[1] Very precise measurements of quantities other than atomic weights, however, have recently been made which show that small variations in isotopic proportions do occur in nature. For example, the density of water varies from source to source by several parts in a million, due to differences in the abundance of the heavy hydrogen isotope H^2.

Attempts have indeed been made, from time to time, to devise means of producing quantities of elements having isotopic compositions different from those found in nature. Until the last few years, these attempts have generally met with indifferent success. Recently, however, there have been developed methods for obtaining very appreciable "separations of isotopes," and the indications are that great progress can be expected in this field in the next few years. It is the object of this paper to describe the methods which have so far been most successful or seem to be most promising, and to mention the important results which have been obtained. Unfortunately, no single method is capable of producing appreciable separation of the isotopes of more than a few elements; we will have to discuss several entirely different types of processes, involving several entirely different bodies of theory, many of which are somewhat complicated in character. Accordingly, it will be impossible to do more than mention the general principle underlying each method discussed.

Methods of separating isotopes

Chemical methods.—The isotopes of an element evidently cannot be separated from one another by the method commonly used in chemistry for the separation of different elements; that is, by mixing the combination to be separated with another element which will combine with one of the constituents but not the others. But, though the chemical compounds into which an atom can enter are determined by the extranuclear electronic configuration, and hence are the same for all isotopes of an element, the rates at which chemical combinations occur depend upon the forces acting upon the atoms involved, and these forces, in turn, depend slightly upon the masses of the nuclei. This makes it easier for one isotope to take part in a particular chemical reaction than for another. One can see how this property can be utilized to produce quantities of an element having isotopic proportions different from normal. It is simply necessary to produce a chemical process in which the reaction rates differ for the different isotopes. At any stage of such a process, the remainder of the starting materials, as well as the newly formed products, will have

isotopic compositions that differ from one another and from the original composition.

Diffusion methods.—Suppose two gases of different densities are mixed together in a porous-walled container. The principle of equipartition requires that the average energy of the molecules be the same for both gases. But if this be true, then the average velocity of the lighter molecules must be greater than that of the heavier ones. (Of course, "lighter" and "heavier" here mean "less massive" and "more massive.") Since it turns out that the rate at which the molecules of a gas diffuse through a porous wall is proportional to their velocity, it is clear that the lighter gas must leak through the walls more readily than the heavier gas. This effect can be utilized in an obvious way in the separation of isotopes that exist in the gaseous state.

Gravity methods.—If two liquids of different densities are mixed, the heavier one settles to the bottom of the container. The same is true of gases. In order to produce some degree of separation of the isotopes of any fluid, therefore, it is simply necessary to put the fluid in a gravitational field, allow it to settle, and then draw, from the bottom, material which is somewhat heavier than normal. The separation can be greatly enhanced by replacing the gravitational field by the much greater fields of force that can be produced by centrifugal devices.

e/m methods.—If one of the extranuclear electrons is removed from an atom of an element, that atom becomes an electrically charged particle. When such a particle passes through an electric or a magnetic field, it is deflected by an amount that depends on the velocity and the charge-to-mass ratio of the particle. Evidently, then, similarly charged atoms of different isotopes will be given different deflections when they are, in some way, shot through any arrangement of electric and magnetic fields. This provides another general method for the separation of isotopes.

Photochemical methods.—It has already been mentioned that certain spectral lines can be produced (in a discharge tube, for example) by one isotope of an element which cannot be produced by any other isotope of that element. Conversely, if radiation of an appropriate frequency is passed through a gaseous mixture of isotopes, it will be absorbed by the atoms of one of the isotopic constituents, but not by the others. Under certain circumstances, such absorption of radiation leaves the atoms of the gas in an excited state that facilitates their chemical combination with another gaseous element which may be present in the absorbing chamber. After the irradiation, the resulting compound may be removed from the original gases by chemical means. This compound (ideally) will contain atoms of only the one isotope of the absorbing gas.

Before going farther, it is of interest to point out some fundamental differences between the foregoing methods of isotopic separation. We can distinguish two general types of separation methods: those in which the end product contains atoms of all the isotopic species originally present, but in different concentrations than originally; and those in which one or more of the isotopes originally present is missing from the end product. Methods of the first type are really *concentration* or *enrichment* methods; those of the second type are true *selection* methods. Chemical separation and diffusion are concentration processes, for all the isotopes participate in the chemical reaction or diffusion process. Similarly, gravity effects can never completely separate the isotopes of any element. The photochemical method, on the other hand, is a true selection process. This is also true of e/m experiments. Such experiments always employ a beam of charged atoms which are deflected in various ways by electric and magnetic fields. If the deflection of a moving charged particle depended only on its e/m ratio, it is clear that particles of different mass m would be completely separated from one another in the final deflected beam. The fact that the deflection of a moving particle depends also on its velocity complicates the experimental arrangements but does not alter the completeness of the ensuing separation. Since there are two parameters, m and v, involved in a deflection, two successive selection processes are required instead of one. If the first process selects from the original group of charged atoms those of a common velocity, then the second process can easily separate from this number those of a common mass. Or the first selection could be made on the basis of energy and the second on the basis of momentum, etc. The in-

struments performing these operations are, of course, mass spectrographs.[2]

We will now discuss various selection and enrichment methods in more detail.

Selection Methods

Mass-spectrographic methods

While every mass spectrograph is intrinsically an isotope separator, the design requirements for an instrument used to separate isotopes are quite different from those for an instrument used to detect the presence and measure the mass of isotopes. The latter, usual, type of mass spectrograph involves very weak ion beams which must be focused, in an exceedingly precise manner, on a photographic plate. For separation purposes, on the other hand, the photographic plate must be replaced by some sort of container with an opening so placed as to collect the atoms of one isotope to the exclusion of all others; and the ion beam must be enhanced as much as possible, so as to increase the quantities obtained. The requirement that the collector be able to exclude all except the desired isotope is not nearly as stringent a focusing requirement as must be imposed on the other type of instrument. This is fortunate, for intense beams and poor focusing generally go hand in hand.

A type of mass spectrograph[3] has been devised which is capable of yielding rather large quantities of the separated isotopes of potassium, lithium, and rubidium. A compound of the element whose isotopes are to be separated is made of such a nature that, when raised to a high temperature, it emits large quantities of charged atoms of the element in question. These ions, from an extended source, are accelerated to a common energy by an electric potential of several thousand volts, and are then passed between the pole pieces of an electromagnet, which are shaped so as to bring to a focus all the ions of one of the isotopes at a point where they can be collected. In this way the isotopes 6 and 7 of lithium, 39 and 41 of potassium, and 85 and 87 of rubidium have been practically completely separated from each other. The quantities of separated isotopes so collected are of the order of several milligrams.

These seem really noteworthy results, when one considers that it has been found possible[4] to perform disintegration experiments on 10^{-8} gm of one of the isotopes of lithium, which had been separated by a mass-spectrographic method. Unfortunately, mass-spectrographic separations are limited to those elements for which intense ion sources can be obtained. At present, there are very few elements for which such strong sources are available.

Photochemical methods

Although in principle the separation of isotopes photochemically is a true selection process, the separations which have actually been obtained are by no means complete. For example, one group of investigators[5] irradiated phosgene vapor with ultraviolet, monochromatic radiation for six months in order to produce one-third of a gram of chlorine having an atomic weight of 35.430, as compared with 35.455 for ordinary chlorine. However, another investigator, Zuber,[6] also using a photochemical method, was able to produce mercury in which the isotopes 200 and 202 were four times as abundant as in normal mercury. His irradiations lasted for only a few minutes, and the quantities obtained were of the order of 5×10^{-8} gm.

A brief consideration of Zuber's experimental method will throw some light on the fundamental difficulties of the photochemical method, and will explain why the separations which can be obtained are not complete.

If mercury vapor is irradiated by the spectral line 2537A produced by a mercury arc lamp, some of the atoms of the vapor will absorb the radiation and become excited. If there is present some oxygen, these excited atoms will combine with atoms of oxygen to form an oxide which can readily be removed from the mercury-oxygen mixture. But the line 2537A of mercury is in reality a group of lines, of very slightly different wave-lengths, each line being due to atoms of certain of the eight isotopes of mercury. If one could filter from his source of radiation only that component of the 2537-line produced by Hg^{200}, for example, and irradiate mercury vapor with it, then only Hg^{200} might be expected to be present in the oxide

[2] For a thorough discussion of the principles involved the reader is referred to a paper by W. Bleakney, Am. Phys. Teacher **4**, 12 (1936).

[3] Smythe, Rumbaugh and West, Phys. Rev. **45**, 724 (1934); Smythe and Hemmendinger, Phys. Rev. **51**, 178 (1937); Hemmendinger and Smythe, Phys. Rev. **51**, 1052 (1937); Rumbaugh, Phys. Rev. **49**, 882 (1936).

[4] Oliphant, Shire and Crowther, Proc. Roy. Soc. **146A**, 922 (1934).

[5] Kuhn and Martin, Zeits. f. physik. Chemie **21B**, 1–2, 93 (1933).

[6] Zuber, Helv. Phys. Acta **9**, 4, 285 (1936).

subsequently formed. Zuber did something of this sort by the use of a Mrozowski filter. Such a filter consists of a tube of mercury vapor in a magnetic field. When a magnetic field is applied to an absorbing vapor, the wave-length which any isotope is capable of absorbing is shifted, so that, for example, the isotope Hg^{198} can be made to absorb the line originally emitted by atoms of the isotope Hg^{202}. By means of a suitable arrangement of magnetic fields, Zuber found it possible to bring to the chamber in which the separation took place radiation which was capable of exciting only the isotopes 200 and 202 of mercury. Imperfect filtering, of course, would have prevented complete separation. Similarly, incomplete separation would have resulted from secondary reactions, such as exchange of the mercury in the vapor for atoms of mercury in the oxide, or collisions of an "excited" mercury atom with an unexcited one, and the resultant transfer of the state of excitation to the second atom. Such secondary processes are often present and must limit the separation in any photochemical experiment.

Enrichment Methods

The general method remaining to be discussed is the *concentration* or *enrichment* method—wherein, from the very nature of the process, a complete separation of isotopes can never be achieved. This method generally works as follows. A liquid or gas containing a mixture of isotopes is subjected to some sort of process that removes some of the atoms of each of the isotopes originally present. In general, the ratios of the rates at which the various isotopes leave the original substance differ by not more than one or two percent from the ratios of their abundances. Consequently, the isotopic composition of the material taken from the original substance differs only negligibly from that of the starting material. But suppose that the removal of atoms from a starting substance is continued until all but a small fraction of those originally present have been removed. Suppose further, for simplicity and also because this is the case in so many experiments, that there are only two isotopes involved. For definiteness, let us assume that the lighter isotope is the more easily removed. Then, clearly, as the quantity of material is diminished by a process which favors the loss of the lighter atoms, the residue will become steadily enriched in the heavier isotope, and the smaller the residue becomes, the greater will become the relative abundance of this isotope. Specifically, we may write

$$dh/dt = kN_h, \qquad dl/dt = rkN_l,$$

where dh/dt and dl/dt are the number of heavy and light atoms, respectively, removed per unit time from the starting substance, and N_h and N_l are the densities of those atoms in the residue. The ratio r of the specific rates of discharge of the two isotopes is determined by the particular chemical or physical process involved in their removal.

The second equation may be divided by the first to give

$$dl/dh = rN_l/N_h = dN_l/dN_h$$

or

$$N_l/N_h = cN_h^{r-1}.$$

Initially, $N_l/N_h = (N_l/N_h)_0$, and we get

$$\alpha = N_l/N_h \div (N_l/N_h)_0 = (N_h/N_{h0})^{r-1} = (N_l/N_{l0})^{(r-1)/r},$$

where α, the "enrichment factor" of the experiment, is the factor by which the abundance of the lighter isotope relative to that of the heavier is increased in the residue.

For example, suppose that one wishes to separate the isotopes of neon by allowing a large quantity of neon gas to diffuse through a porous wall until only a small quantity remains. For such a thermal diffusion, the isotope Ne^{20} passes through the porous wall more rapidly than Ne^{22}, in the ratio $(22/20)^{\frac{1}{2}} = r$. Normally, for neon gas, $(N_l/N_h)_0 = 9:1$, approximately. Accordingly, $N_l/N_{l0} \approx$ (Final volume of gas)/(Initial volume of gas), or

$$\alpha = \frac{V_f}{V_i} \exp \frac{(22/20)^{\frac{1}{2}} - 1}{(22/20)^{\frac{1}{2}}}.$$

Suppose, then, that one commences with 10^6 ml of gas, and allows all but 1 ml to diffuse away. Then $1/\alpha \approx (10)^{6/22} \approx 2$; that is, the relative abundance of Ne^{22} in the residue is twice normal.

Such a means of extracting from a large quantity of substance, in a single step, a small amount having an appreciably changed isotopic composition, will be referred to in subsequent pages as the "method of residues."

There is another way of producing appreciable concentration of an isotope which would at first seem to be capable of producing only a negligible enrichment. Consider again the situation just discussed, wherein a mixture of two isotopes is subjected to a process that removes the lighter component slightly more readily than the heavier. Suppose, this time, we start with a large quantity of material and allow only a fraction of it to

be removed. This fraction, which we will collect, will be slightly enriched in the lighter isotope of the composition. Now let us forget about the original material, and subject the fraction we have collected to the same sort of removal process whereby *it* was acquired. The fraction of this fraction so collected will be still richer in the lighter isotope, etc. The result of a number n of such fractionations performed successively, will be an increase in the relative abundance of the lighter isotope by a factor of $(\alpha)^n$, where α, the elemental enrichment factor for this experiment, is the factor by which N_l/N_h in the removed fraction exceeds that in the substance from which it was removed.

It is evident that α must depend not only on the physical or chemical process removing one isotope more readily than the other from the starting substance, but also upon the fraction of the starting substance removed in each fractionation. If the fractionation were allowed to proceed until the material was exhausted, for example, α would simply equal unity, and no isotopic enrichment would be possible. If, on the other hand, the fraction removed is very small, α has a maximum value which is determined entirely by physical or chemical, rather than geometric, considerations; but the quantity thus made available for succeeding fractionations is small. In practice it is generally necessary to strike a compromise between large values of α and reasonable quantities of end product.

In the case of the neon isotopes, $\alpha_{max} = (22/20)^{\frac{1}{2}} = 1.05$; that is, to increase the relative abundance of Ne^{20} by a factor of 2, about 16 fractionations would be needed. If each fractionation removed one-tenth, say, of the gas removed in the preceding fractionation, and the end product was 1 ml, 10^{16} ml would be needed at the start.

We are now in a position to discuss in more detail some of the experiments whereby isotopes have been separated by enrichment methods. It is possible to precede this discussion by a generalization; namely, *with but few exceptions, appreciable separations of isotopes are made only when an isotope-discriminating process can be employed of such a character that it can be incorporated in a method of residues or of successive fractionations.* The experiments to be described differ widely in the isotope-discriminating processes they employ, and in the mechanics of their experimental arrangements; but it may be said of nearly every one that the enrichment factor of the elemental process is only a few percent greater than one, and that appreciable separations are the result of multiple processes, residue processes, or a combination of the two.

Chemical methods

By a "chemical method" of separating isotopes is meant a method whose isotope-discriminating process is chemical or physico-chemical in character. The phenomena most commonly employed are:

(a) Differences in vapor pressures of the various isotopic components of a liquid.

(b) Differences in the forces tending to hold the various isotopic atoms in chemical compounds.

(c) Differences in the adsorptive or absorptive forces tending to hold the various isotopic atoms on a surface or in another substance.

Thermodynamical considerations lead to a generalization that can be made about chemical separation methods; namely, *the enrichment will usually increase as the temperature is decreased.* We shall see that this principle has made possible some large separations in a few instances.

Separation of the isotopes of hydrogen.—Hydrogen is distinctly in a class by itself so far as the separation of isotopes is concerned. This is a consequence of the very large percentage difference in the masses of its isotopes, which is attended by correspondingly large differences in the properties made use of in isotope separation. Consequently, the isotopic enrichments possible with hydrogen are very much greater than those that can be achieved with any other element, a fact that should be borne in mind in evaluating the results of enrichment experiments.

The isotope H^2 was first concentrated by a method which depends on the fact that it has a lower vapor pressure, above liquid hydrogen, than H^1. It was found[7] that, when 4 l of liquid hydrogen is evaporated to 1 ml, at a pressure just above the triple-point value, the $H^2 : H^1$ ratio increases from 1 : 4000 to 1 : 800. This is a pure "method of residues" experiment wherein r is about 1.2.

Shortly after the discovery of heavy hydrogen,

[7] Urey, Brickwedde and Murphy, Phys. Rev. **39**, 164; **40**, 1 (1932).

it was found that a great enrichment of H^2 could be produced by a method of residues involving the electrolysis of water. When water is electrolyzed, H^1 is liberated at the cathode more readily than H^2. The specific discharge ratio r depends on the conditions of the experiment, but is quite large—generally from 4 to 8. This method has been developed until it is neither a very long nor a difficult task to produce several grams of water in which the hydrogen is practically pure H^2. The chemical process involved in the separation of isotopes by electrolysis is complex in character; there are several factors to which the enrichment might be attributed. Electrolysis involves: dissociation of the molecules [b], movement of the ions through the electrolyte, adsorption of the ions on the electrode [c], recombination of the ions to form molecules [b], absorption of the resulting gas and subsequent evaporation from the electrolyte [a]. The letters [a], [b], etc., refer to the foregoing classification of the phenomena which may be made use of in chemical enrichments. It is evident that there are several possible isotope-discriminating processes involved in electrolysis. (Since there is good reason to believe that the ionic mobilities are the same for all isotopes of an element, this is not considered a likely enriching process.) Actually, it is thought that the controlling process is usually the adsorption of the hydrogen ions on the electrode and their ensuing combination to form neutral molecules.

Another chemical method of separating the isotopes of hydrogen has been employed quite lately with unusual success.[8] It has been known for some time that H^2 is more readily adsorbed on a charcoal surface than H^1. In accordance with the general thermodynamical principle already pointed out, the amount of such a separation is increased when the adsorption takes place at a low temperature. It has been found, however, that the enrichment factor of such a separation of the hydrogen isotopes increases almost discontinuously (provided certain precautions are taken which it is not necessary to go into here) as the adsorption temperature drops below $-207°$C. Thus, if hydrogen is adsorbed on charcoal at, say, $-220°$ and the temperature is raised to $-210°$, then only $H_2{}^1$ molecules can be pumped off, the H^2 atoms remaining practically completely adsorbed in the charcoal. In this way almost complete separations of the different isotopic varieties of hydrogen molecules have been reported. Such "critical adsorption temperatures" are known to exist for other gases, and it is not improbable that the same method may, in the future, yield appreciable separations of isotopes other than those of hydrogen.

[8] Peters and Lohmar, Zeits. f. physik. Chemie **180A**, 51 (1937).

An enrichment method which is applicable only to the isotopes of hydrogen makes use of the fact that H^1 atoms diffuse through hot palladium more readily than atoms of H^2. This is really a chemical enrichment process, for the difference in the rates of diffusion is too large to be due simply to the difference in the thermal velocities of the atoms. Some sort of chemical forces apparently act on the diffusing atoms and facilitate the transmission of the lighter isotope relative to that of the heavier. For example,[9] when 99 percent of a gaseous mixture of H^1 and H^2 is allowed to diffuse through palladium, the residue is enriched in H^2 by a factor of 10. The equations worked out for the method of residues show that $r=2$ for this experiment. Thus, this method cannot compare favorably with the method of electrolysis, for which r may be as large as 7 or 8.

Separation of the isotopes of elements other than hydrogen.—Chemical methods have also been applied successfully with neon, oxygen, nitrogen, and lithium. The method of successive fractionations was employed in all four cases, and the experimental technic was fundamentally the same for the work on neon, oxygen, and nitrogen. In each case some sort of "fractionating column" was employed. The apparatus in Fig. 1 was designed for work with neon[10] and is perhaps the simplest in operation. Suppose the entire apparatus is initially at the temperature of liquid hydrogen. The liquid neon in the bottom pan is heated, and neon vapor travels up through the first funnel and condenses on the cooler material of the second pan. But the vapor pressure of Ne^{20} is greater than that of Ne^{22}. Hence the liquid condensing in the second pan is slightly richer in Ne^{20} than that in the bottom pan. This second pan soon becomes warmed as it is covered with liquid neon, and vapor then travels up the second funnel to the third pan. This vapor

[9] Harris, Jost and Pearse, Proc. Nat. Acad. Sci. **19**, 991 (1933).

[10] Keesom, van Dijk and Haantjes, Physica **1**, 1109 (1934); **2**, 981 (1935).

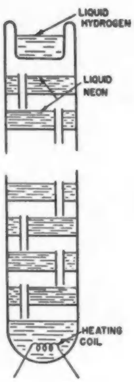


FIG. 1. Fractionating column used with neon. (Keesom, van Dijk and Haantjes.)

is still richer in Ne^{20}, etc. Finally, the neon evaporating from the top pan is condensed on the liquid-hydrogen-cooled condenser at the top of the apparatus and drips down again into the top pan. This causes liquid to overflow to the next lower pan, which in turn displaces liquid to the next pan, etc. When equilibrium is finally established, the amount of neon rising as vapor from one pan to the next is exactly counterbalanced by an identical amount of liquid, of the same isotopic composition, going down. The concentration of Ne^{20}, therefore, increases from the bottom to the top of the apparatus, according to the relation

$$(N_l/N_h)_p=(N_l/N_h)_0\alpha^p,$$

where $(N_l/N_h)_p$ is the ratio of the abundances of Ne^{20} and Ne^{22} in the pth pan from the bottom, and α is the elemental enrichment factor of the experiment. When the boiling is very slow, α approaches the ratio of the vapor pressures of Ne^{20} and Ne^{22}.

By the use of an apparatus of 60 pans, it was found possible to collect, in about 90 hours, 140 l of neon gas in which the $Ne^{22}:Ne^{20}$ ratio was about four times normal. A larger apparatus, supplemented by successive "successive fractionations" of this type, yielded 4 l of gas with a $Ne^{22}:Ne^{20}$ ratio 13 times the value for ordinary neon.

It should be noticed that the large enrichments obtained in this work were due in great part to the low temperatures at which this type of fractionation can be carried out. In the work with oxygen, nitrogen, and lithium, the experiments were performed at, or near, room temperature, but a greater number of "pans," or their equivalent, served to compensate for this disadvantage.

The oxygen isotopes have been separated[11] with a fractionation column in which water was the working substance. The separation was made possible by the fact that the vapor pressure of H_2O^{16} is slightly greater than that of H_2O^{18}. A system of coaxial stationary and rotating cones made it possible to build an apparatus of over 600 "pans" in a reasonable space. With it, 200 ml of water was produced in about 300 hours, having an $O^{18}:O^{16}$ ratio nearly five times that of ordinary oxygen.

The same apparatus was used[12] to concentrate N^{15}. The working substance here was a solution of ammonium sulfate, from which NH_3 gas evaporated, and into which it subsequently was redissolved, the $N^{14}H_3$ having a higher vapor pressure than the $N^{15}H_3$. In such an experiment the liquid and vapor are not directly interconvertible, as in the case of a pure working substance which simply evaporates and condenses; and the success of the separation depends on the finding of means whereby the proper conversion of liquid to vapor, or *vice versa*, may be brought about. Such means were devised, and several grams of NH_3 gas were collected, in which the $N^{15}:N^{14}$ ratio was about 6.5 times that of ordinary nitrogen.

An appreciable chemical separation of the isotopes of lithium has been achieved by a very ingenious scheme.[13] Tiny drops of lithium amalgam were sprayed down through a long column of lithium chloride (or lithium bromide) solution. When lithium amalgam was thus brought into intimate contact with such a salt, it turned out that there was a slight tendency for the Li^7 atoms in the amalgam to be replaced by Li^6 atoms from the salt. By the time a drop of amalgam reached the bottom of the column of electrolyte, the lithium in it was slightly enriched in the lighter isotope. After a quantity of amalgam had accumulated, it was removed and subjected to a process that extracted the lithium, which was

[11] Huffman and Urey, J. Ind. Eng. Chem. **29**, 531 (1937).
[12] Urey, Huffman, Thode and Fox, J. Chem. Phys. 5, 856 (1937).
[13] Lewis and Macdonald, J. Am. Chem. Soc. **58**, 2519 (1936).

converted, in turn, into electrolyte and added to the bottom of the column. This caused an equal quantity of electrolyte, rich in Li^7, to be driven out of the top of the column, then more lithium amalgam was sprayed down, etc. Each cycle resulted in an increase in the $Li^6 : Li^7$ ratio of the amalgam which accumulated at the bottom. The experiment was continued until 10 l of amalgam had passed through the electrolyte. A fraction of a gram of lithium, having a $Li^6 : Li^7$ ratio about twice normal, was the result.

Enrichment of lithium in the lighter isotope has also been accomplished recently by an electrolytic method.[14] About one-tenth of the lithium was removed by electrolysis from a solution containing 9000 gm of lithium chloride. This fraction was itself converted into lithium chloride and used for a second electrolysis. One-tenth of this was electrolyzed, the lithium extracted and reconverted into electrolyte. The result of the third electrolysis was 0.9 gm of lithium in which the $Li^6 : Li^7$ ratio was about 1.7 times that of ordinary lithium.

Nothing has been said about the method of calculating the elemental enrichment factor of a chemical separation. Such a calculation may usually be made, with some degree of accuracy, by statistical thermodynamical methods based on the use of constants obtained from spectroscopic data. In the work of Lewis and Macdonald[13] on the isotopes of lithium, however, it was not even possible to predict in advance which isotope would be concentrated in the amalgam!

Diffusion methods

If a gaseous mixture of light and heavy molecules, of masses m_l and m_h, is confined in a porous-walled vessel and the surrounding space is evacuated, molecules will escape through the walls at the rates $dl/dt = kN_l v_l$ and $dh/dt = kN_h v_h$, where v_l/v_h, the ratio of the thermal velocities of the two types of molecules, is the specific discharge ratio r of the process. The principle of equipartition leads to the well-known relation $r = (m_h/m_l)^{\frac{1}{2}}$. We have already seen how this difference in thermal velocities makes possible a separation of gaseous isotopes, either by the method of residues or by the method of successive processes. However, the amount of enrichment possible in a practical experiment, employing a reasonable amount of gas, we have seen to be discouragingly small for either of these methods. Particularly striking, therefore, was the success of a diffusion method[15] in producing quantities of neon gas in which either Ne^{20} or Ne^{22} was spectroscopically *absent*. This was accomplished by a simple, yet exceedingly ingenious, apparatus which resulted in an entirely automatic separation process making use of both the method of residues and of multiple diffusions.

Figure 2 represents a mercury diffusion pump

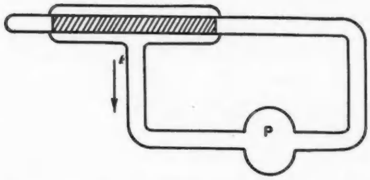


FIG. 2. Separation member for diffusion apparatus. (G. Hertz.)

P forcing gas into one end of a hollow, porous-walled tube, and pulling it out again through the wall of the same tube. Let us follow a given group of molecules as it moves from the right to the left end of the tube. This group consists of a mixture of light and heavy molecules. As the group travels towards the left end of the tube, molecules continually escape by diffusion through the wall. Consequently, the population of the group becomes steadily less. Further, since the diffusion process favors the removal of light molecules, the relative abundance of the heavy molecules in the group must increase steadily. Finally, at the extreme left end of the tube, the number of molecules remaining in the group with which we started approaches zero, and the relative abundance of the heavy molecules approaches a large value. The enrichment of the gas in the heavy molecules would approach infinity, if there were no mixing of the gas along the tube length; that is, if our original group of molecules did not spread out and did not receive molecules from other parts of the tube. Actually such mixing does take place, so that the concentration gradient remains finite.

[14] Holleck, Zeits. f. Elektrochem. **44**, 111 (1938).

[15] Hertz, Zeits. f. Physik **79**, 1.2, 108 (1932); Harmsen, Zeits. f. Physik **82**, 9–10, 589 (1933).

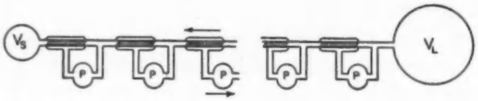


FIG. 3. Multi-stage diffusion apparatus.

With such a "separation member" as this, isotopic enrichment is obtained by the method of residues. The next step is to add together such separation members in series (Fig. 3). With such an apparatus, the enrichment factor α of a single member is much greater than the specific discharge ratio of a simple diffusion. The total enrichment is α^m, where m is the number of separation members connected in series. Again one may note that, if the mixing of the gas along the porous tubes is small, the enrichment factor of each member is large. But, at the same time, the rate of transfer of gas from one member to another is small, so that a long time is required for equilibrium to be reached. These factors can be controlled to some extent by the cross section and porosity of the tubes, or by the modification of the connections shown in Fig. 4. In this arrangement of apparatus the equilibrium time may be shortened (at the expense of the enrichment factor) by increasing the $l_1 : l_2$ ratio.

Apparatus of this type operates at a gas pressure of a few millimeters of mercury and requires from two or three hours to a day or so to reach equilibrium, depending on the number and construction of the separation members. Ordinarily 300–400 ml of enriched gas (i.e., 2 or 3 ml at S.T.P.) is the result. In the original separation of the isotopes of neon, already referred to, an apparatus of 48 members was employed. An apparatus of 35 members[16] has proved adequate to produce methane gas in which the $C^{13} : C^{12}$ ratio is 16 times that of ordinary carbon, and nitrogen gas with an 11-times normal $N^{15} : N^{14}$ ratio. Exceedingly pure heavy hydrogen can, of course, be produced[17] in this way.

More recently, the fact that light molecules will diffuse across a stream of mercury vapor more rapidly than heavy ones has been used[18] to develop a mercury diffusion pump which circulates light gas more readily than heavy gas. By the use of a scheme of connection similar to that of Fig. 3, in which the porous tubes were replaced by ordinary constricted tubing, the $O^{18} : O^{16}$ ratio in water vapor has been increased by a factor of 50, whereas the $A^{36} : A^{40}$ ratio in argon has been increased by a factor of 300.

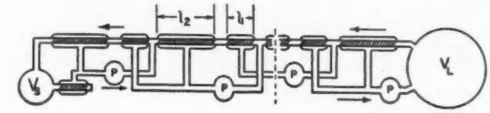


FIG. 4. Alternative form of diffusion apparatus.

Gravity method

The separation of isotopes by centrifuging has not, in the past, been possible, owing to the exceedingly high peripheral speeds required. It is easy to show that the enrichment factor for a mixture of two gaseous isotopes in a centrifuge having a peripheral speed V is

$$\alpha = e^{(V^2/2RT)(M_h - M_l)},$$

where M_h and M_l are the molecular weights of the two kinds of gas. Centrifuges have recently been constructed[19] that make possible a peripheral speed of 8×10^4 cm/sec. If, in addition, $T=300°$K and $M_h - M_l = 2$, then $\alpha = 1.29$. This means that, if a gaseous mixture of two isotopic constituents whose molecular weights differ by 2 gm/mole is whirled in such a centrifuge at a temperature of 300°K, the heavier constituent will accumulate on the circumference of the centrifuge until the ratio of the molecular densities of the heavy and light gas in that vicinity is 1.29 times their ratio on the axis. Hence, if a group of such centrifuges could be run in series, with the gas near the axis of one being introduced to the next through holes in its periphery, a very appreciable isotopic enrichment might be attained. If this could be done at a low temperature, the enrichment could be greatly increased. At 20°K, for example, α is 47 instead of 1.29!

A further promising feature of the centrifugal method is the dependence of the enrichment on the difference of the molecular weights of the isotopes involved rather than on their ratio, as

[16] Wooldridge and Smythe, Phys. Rev. **50**, 233 (1936).
[17] Harmsen, Hertz and Schutze, Zeits. f. Physik **90**, 11–12, 703 (1934).
[18] Hertz, Zeits. f. Physik **91**, 11–12, 810 (1934); Barwich, Zeits. f. Physik **100**, 3–4, 166 (1936); Barwich and Schutze, Zeits. f. Physik **105**, 7–8, 395 (1937); Kopferman and Kruger, Zeits. f. Physik **105**, 7–8, 389 (1937).
[19] Beams and Haynes, Phys. Rev. **50**, 491 (1936); Beams and Masket, Phys. Rev. **51**, 384 (1937).

in the diffusion experiments. This makes the centrifugal method of isotope separation as applicable to heavy, compound molecules as to light, simple ones.

Thus far only preliminary experiments have been made towards the separation of isotopes,[19] but, on the whole, the method appears to be promising.

In this summary of the results of research on the separation of isotopes, we have found it natural to divide the work into two classes—experiments that produce appreciable fractions of a gram or more of material having a small change in isotopic composition, and experiments that produce a few milligrams or less of material having a large change in isotopic composition. Results of the first class are produced by chemical separation experiments; those of the second class are produced principally by diffusion and mass spectrographic experiments. Sometimes, to be sure, the small scale experiments produce enrichments that are not much greater than those produced by some large scale experiments, but in general large quantities have tended to accompany small separations. Complete separation of appreciable quantities (of the order of 1 mg or more) of the isotopes of an element has been approached, in the cases of lithium, potassium, and rubidium, by mass-spectrographic methods; in the case of hydrogen, by electrolysis and by gaseous diffusion methods; and in the case of neon, by a gaseous diffusion method.

Arthur Gordon Webster—Physicist, Mathematician, Linguist, and Orator

On the remarkable career of the versatile physicist who founded the American Physical Society, and who could lecture on every branch of mathematical physics and do it in several languages

A. Wilmer Duff
Emeritus Professor of Physics, Worcester Polytechnic Institute, Worcester, Massachusetts

To be asked to give a brief account of the life and scientific work of one who stands high among American physicists of a past generation is, indeed, a great honor, though it is one that I fear I hardly deserve. The task would not seem to be a difficult one, so far as it concerns the late Professor Webster's attainments and scientific activities, for of these there are ample records. But the honor is not devoid of embarrassment when the writer is also asked to give some account of the personality and general activities of the man about whom he writes, especially when these activities were so varied and the personality was so complex that any brief account of them must necessarily present a very imperfect and, perhaps, misleading picture.

To know something of the spirit that animated eminent men who had the same professional interests as ourselves should be a stimulus to us in our own work, and it is natural that we should also desire to know what manner of men they were outside their studies, laboratories, and classrooms. Even if the account should reveal that they were not exempt from the mistakes and weaknesses of ordinary men, we may hope to learn from their failures as well as from their successes. But the reliability of any attempted picture of a very complex personality might well be questioned, if it depended on the evidence of a single observer, however well-intentioned. Hence, except where the opposite is obvious or is indicated, I shall restrict it to features that can be confirmed by independent evidence, though it will not be necessary to confuse the narrative by halting at each step to quote authorities.

Background and Education

While we cannot, in general, disentangle the strands of heredity and account for a man's personality by his descent, in Webster's case certain features of ancestry seem curiously suggestive of such a relationship. He was born in Brookline, Massachusetts, on November 28, 1863, and was

in the ninth generation of descent from an Englishman, John Webster, who settled in Ipswich, Massachusetts, in 1638. Among his other ancestors was David Webster, who founded Plymouth, New Hampshire, and was a lieutenant-colonel of New Hampshire troops in the war of the Revolution. Webster's father, William E. Webster, a prosperous citizen of Brookline, was so highly esteemed by his son that the latter, it is said, always consulted his father on all important matters. We seem to see in this ancestry the promise of the dignity of person and bearing that was one of Webster's most noticeable characteristics. His Scotch ancestry, indicated by the Gordon in his name, was at least suggestive of his later activity as the chief interpreter in this country of the work of the great Scotchman, James Clerk Maxwell, whose fundamental equations in electromagnetism are the foundations of the subject. Finally, a strain of Irish blood, inherited from his mother (born Mary Shannon), might account for Webster's marked gifts for dramatic expression and also for a certain aggressiveness that did not, however, usually create permanent antagonism. Even if this account be fanciful, it must be admitted that Webster's personality showed markedly different aspects in different circumstances and this inconsistency laid him open to considerable criticism.

Arthur Gordon Webster, 1863–1923.

The Webster family having changed their place of residence, Webster prepared for college at the Newton High School and entered Harvard in 1881. His record as a student was an exceptionally brilliant one, for he seemed to be able to stand high in any subject to which he gave attention. His chief interest was, however, in mathematics and mathematical physics, which he studied under Byerly, B. O. Peirce, Hall, Trowbridge, and Wolcott Gibbs, graduating with highest honors in those subjects in 1885. Living at home in a town ten miles from the university and deeply interested in his work as a student, Webster took no part in athletics, though he was physically very robust. In fact, he was never seriously ill at any time in his life, a result which he attributed (in his class report of 1910) to "the use of the gymnasium then and since and the avoidance of athletic contests." At his graduation he was the valedictorian of a class that contained an exceptional number of men who were very successful in after life.

While accomplishments in a college course are

far from reliable as an augury of future success, the personal characteristics displayed are likely to be persistent. In this connection it will be interesting to quote the remarks of one who was a fellow student of Webster's and was interested in the same subjects, Alexander G. McAdie, later professor of meteorology at Harvard:

> We all recognized Webster's ability. He took the lead and we felt he deserved his place. It is to the credit of all of us that there were no small jealousies nor hard feelings incident to competition. In a way this was due to Webster's personality. He was pleasant and friendly and never seemed to take to himself special credit. We knew him as methodical, systematic and level-headed, and, while assertive enough, not offensively so. The trait of speaking out, which later in life was to cause criticism, he had then; but we were always ready to hear him and were gainers by doing so.

Webster spent the year following graduation as instructor in mathematics and physics at Harvard and the four following years as Parker Fellow abroad, mostly in Berlin under Helmholtz and Kundt. In Berlin he immediately formed one friendship that lasted the rest of his life; namely, with Joseph S. Ames, afterwards professor of physics at Johns Hopkins University. Of this friendship, Professor Ames says:

> My acquaintance with Webster dates back to the fall of 1886, when I entered the Physical Laboratory of Helmholtz at the University of Berlin and met Webster standing in the entry outside Professor Helmholtz's room, where all new students were invited to assemble. From that time until his death Webster and I were close and intimate friends. . . . I cannot speak too highly of those qualities of heart and mind which make for friendship and which everyone who knew Webster recognized in him. . . . He was a man of remarkable versatility, having great power in mathematics and unusual ability to learn and feel foreign languages. . . . I have never known a man with such an unusual equipment.

Between semesters at Berlin, Webster traveled in Italy, Austria, Denmark, and Sweden, devoting a good deal of attention to languages, and he also spent several semesters at the Universities of Paris and Stockholm. Another fellow student in Berlin was Michael Pupin, afterwards professor of electromechanics at Columbia University, a distinguished physicist and inventor. The acquaintance with Pupin in Berlin ripened into the closest friendship of Webster's life. How strong the bond of sympathy between them was may be gathered from Pupin's interesting book, *From Immigrant to Inventor*, in which he wrote of Webster: "Lincoln's words 'With malice toward none, with charity for all' describe Webster's kindliness of heart better than any words I could find." On another occasion, Pupin narrated the following interesting circumstance:

> During a short visit to Paris in 1887, Webster and I made the acquaintance of many Serbian students who were studying there. Several of them became in after years the guides of the destiny of Serbia. I never visited Belgrade without taking away with me many cordial greetings for Webster from these acquaintances of many years ago. I often heard them say to me: "If Americans are like Webster, then it is no wonder that you prefer to live in America." . . . When he stood up for right and justice and truth he was fearless and full of fight, and he reminded you of the Massachusetts men who fought at Bunker Hill. When you addressed yourself to his sympathy, he was as mellow and gentle as the gentlest saint in Heaven.

While in Berlin Webster met Elizabeth Monroe Townsend, daughter of Captain Robert Townsend of the United States Navy. They were married at Syracuse, New York, in 1889, before Webster graduated from Berlin.

Teaching and Book Writing

In the year 1890 in which he received his Ph.D. degree at Berlin, Webster was appointed docent in mathematical physics in the new Clark University in Worcester, Massachusetts. Michelson was head of the department of physics, but went to the University of Chicago two years later. Webster then became head with the title of assistant professor, and in 1900 he was promoted to a full professorship, the position which he occupied until his death in 1923. Such a position had decided advantages for a man of his tastes, for the work of teaching the mathematical theory of physics and directing research brought him into contact only with advanced students. Clark University was, at that time, wholly a post-graduate institution, with a staff of distinguished specialists and an eminent psychologist as president.

As a lecturer on mathematical physics, Webster was highly effective and won the warm admiration and regard of his students. One of the earliest of them, Albert P. Wills, late professor

of mathematical physics in Columbia University, gave the following graphic sketch of the young enthusiastic lecturer:

> Well do I recall the first lecture of his which I attended. Promptly at ten o'clock the lecturer appeared. We of the class were greatly impressed by his youthful and dignified presence. The lecture was hardly begun before we began to suspect that we were setting forth on a project of serious import; it was not half over before any lingering doubts on the matter had disappeared; and visions loomed of nightly vigils over our notes and books to the end that we might at least follow on the trail of this man who could say so much and write so much in one short hour in the classroom. But in the course of time we arrived at full appreciation of his masterly exposition of the intrinsically difficult subjects which he taught.

That the lecturer did not underrate the importance of the subject into which he was initiating Mr. Wills and his other young students can be seen from the sentence with which he began one of his books: "It is the lofty aim of mathematical or theoretical physics to describe the universe in the most accurate manner." Whether the addition of the word "possible" would have been too much of a concession to human frailty, I do not know. But Webster was essentially a considerate man and did not expect his students to have mastered everything he had taught them, even when they appeared for their oral examination for the Ph.D. degree. I was an interested assistant at these ordeals for many years, and I was always impressed by the mixture of grave dignity and kindly tact with which, at the outset, he set the nervous candidate at ease. The first question or two were apt to be deceptively mild, but they soon plunged into things so strenuously that I was glad I was merely an examiner.

In one respect, at least, Webster was as proficient a lecturer on advanced theory as any that I have known. He was very expert and nearly faultless in blackboard work, being equalled in this respect only by Tait of Edinburgh. Next to them, I would rank Helmholtz (whom I saw in action only once) and Planck (whom I heard frequently). Lower down would come Maxwell (of whom I can speak only by report) and then Kelvin; but my only reason for putting Maxwell above Kelvin is that I think he could not have been worse than Kelvin. It was, in fact, frequently difficult to know what Kelvin was discussing at all when he was really thinking aloud. On one occasion he addressed the Royal Society of Edinburgh on a Monday evening, and Knott (assistant to Tait), who had to report the meeting in *Nature*, had been quite puzzled and appealed to Tait on Tuesday morning to help him. But Tait would not risk it. Just then Kelvin came in to call on Tait and they asked him. After gazing at infinity for a few moments, he said with relief: "Just wait till the *Nature* report is published—that fellow always reports me well."

It is, I suppose, impossible for any of the younger generation of accomplished physicists to imagine the state of the science in this country fifty years ago. There was then no army of highly specialized investigators, following in minute detail the numerous lines of research into which physics has ramified—learning, as someone has humorously expressed it, "more and more of less and less," even of the invisibly small. Instead, there were then only a very few highly gifted pioneers, Rowland, Michelson, Willard Gibbs, Edison, to mention only a few names that are permanently associated with important discoveries, working with a small number of assistants and research students. Even the work of these men was, for the most part, only an offshoot of the tree of fundamental experiment and theory in Europe. Of systematic training in theoretical physics in any broad comprehensive sense, there was little if any.

To give his students this broad sound training, Webster proposed to cover the whole of mathematical physics in his lectures. To anyone who knows what this means in the way of mathematical reading of a difficult kind and its assimilation, coordination and reproduction, the task for one lecturer will seem an immense one, not merely in the mental capacity and power of concentration presupposed, but also in the physical strain entailed. Speaking as one of his contemporaries, I venture to say that no one else in America was at that time qualified for carrying such an undertaking to the stage of success Webster reached. It may be that this work of expounding the work of others over such a wide range (so that little time was left for deep reflection on it at any stage, and the play of imagination required for original thinking was inhibited) had something to do with the lack of fertility

in new ideas that Webster himself, with his characteristic honesty, was wont to confess. On the other hand, it led to the writing of three masterly books, which, through the assistance they gave to others engaged in research, helped greatly in the advances in physics in this country.

Webster's first book was *The Theory of Electricity* (Macmillan, 1897). How extensive the reading in preparation for the work was may be judged from the prefaced list of 44 "works consulted by the author," written in English, French, German, and Italian. That no such comprehensive treatise had been attempted in America is shown by the fact that only one of the 44 books consulted was by an American, and even that one (Peirce's *Potential Function*) was not especially on electricity. At the head of the list stood Maxwell's great *Treatise on Electricity and Magnetism*. Webster explains in the preface that his own book was written because Maxwell's two volumes could not be assigned to the student as a textbook without exposing him to "the severest pangs of mental indigestion," chiefly because of the demands on his mathematical attainments. Webster tried to meet the difficulty by devoting the first half of his volume to an introduction on advanced mathematics and mechanics, so that the word electricity does not appear until the middle of the book is reached, whereas, in English books on the subject, the mathematical and mechanical principles were introduced and explained *passim*, as needed. Webster's method certainly had the advantage that it drew the reader's attention more clearly to the relation between special electrical principles and broader general principles. It suggests, however, the question whether it would not have been wiser to divide the single large volume into two smaller volumes. The material in the first half would have been an admirable and very useful general introduction to mathematical physics.

In the treatment of electricity Webster followed Maxwell in a general way, but he showed the influence of his German training by deducing Maxwell's equations from Hamilton's principle and Helmholtz' cyclic systems. It was certainly to the credit of the great German physicists, Helmholtz, Boltzmann, Hertz, and others that they appreciated so early the importance of Maxwell's work, though I think none went so far as those Germans who thought it was only by a kind of oversight that Shakespeare was not born a German. Of the general qualities of Webster's treatment, I will let one who is a more competent judge speak. Professor Henry Crew, emeritus professor of physics in Northwestern University, said of it: "The elegance and clearness with which Webster has set forth the electromagnetic theory has, in my judgment, never been equalled in English or in any other tongue." While the book is no longer much used as a textbook, because it was written before the advent of the electron, it is of historical interest as the first great treatise on the subject by an American.

Webster's second contribution to the book literature on mathematical physics was entitled *The Dynamics of Particles and of Rigid, Elastic and Fluid Bodies* (Teubner, 1904). Here again the extent to which the writer was a pioneer in America is shown by the fact that of the 60 "works consulted by the author," only one, and that a comparatively elementary book, was by an American. In Webster's compact volume of 588 pages, the essential parts of what students were previously compelled to seek in a dozen English treatises, often in diverse notations, were correlated and expounded with such mathematical elegance and thoroughness that the book became an immediate success and has remained so in the intervening 34 years. Lagrange, in his great *Mécanique Analytique*, had made mechanics a branch of general analysis and called attention to the fact that no diagrams or geometrical considerations, only algebraic expressions, were to be found in his book. From the wisdom of this, Webster, in sympathy with the more practical instincts of great experimental as well as theoretical physicists, such as Maxwell and Kelvin, dissented, while admitting the great value of Lagrange's general method of solving mechanical problems. Believing that, in the attempt to do without pictures or mental images, we rob ourselves of a valuable aid, Webster used them freely in his own book, of which Villino Volterra, professor of mathematical physics in the Royal University, Rome, himself a great authority on such subjects, said:

> Webster had a great facility for learning and mastering all new ideas. His *Dynamics* is a work in which he has treated nearly all the branches of me-

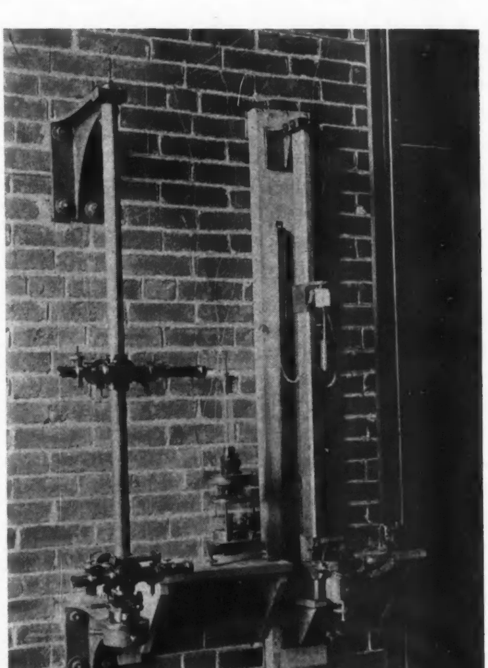
chanics. A large number of theories are to be found there, condensed into a minimum number of pages, without losing either clarity or elegance or profundity. To describe it as a didactical work and as a manual useful to all physicists would be hardly adequate.

The third, and last, book that Webster wrote was on *The Partial Differential Equations of Mathematical Physics*. It was published by Teubner in 1927, four years after Webster's death, being edited by Professor S. J. Plimpton of the department of physics of the Worcester Polytechnic Institute, who had assisted the author in reading and criticizing the manuscript. At the time of Webster's death, half of the book was in uncorrected proof form, the remainder being in manuscript. This book also was a valuable synthesis of material from a large number of sources. Its general aim was to unify the treatment of the various partial differential equations that appear in different parts of physics and are usually solved by a variety of unrelated devices, by showing that they are all special cases of a general equation, the solution of which includes all the special devices. The book met a need that had long been felt and with such success that it was immediately translated into German, and a second English edition was soon called for. It is now used extensively as a valuable reference book in this country and abroad, and part of its contents are of such a practical nature that men in certain industrial research lines find it very useful.

Other Scientific Activities

While there were certain other ways, to be mentioned presently, in which Webster's work helped in the advancement in physics in this country, his three rather remarkable books were, I suppose, his most definite contribution. In preparing them, his attention was, of course, drawn to details in mathematical physics which could be improved or amplified in ways that had not occurred to others. This gave rise to a large number of articles on mathematical and experimental physics, as well as some on pure mathematics, which he contributed to the proceedings of the National Academy of Science, of the American Academy of Arts and Science, of the American Philosophical Society, of the American Mathematical Society, and of the American Physical Society, and to *The Physical Review*, *Nature*, *Science*, and other periodicals. Interesting and useful as these were to those working in related fields, it cannot be claimed that, with a few exceptions to be considered presently, they showed a high order of originality, comparable with the ability he showed in assimilating and coordinating the work of others. To attempt to summarize such diverse contributions would be, I suppose, beside the purpose of these sketches of former leaders in physics in America.

The three exceptional papers that seem to call for special mention were on electrical oscillations, absolute measurement of sound, and acoustic impedance, respectively. If I may again be permitted to be a little fanciful, I would be inclined to call them, from their chronological order and

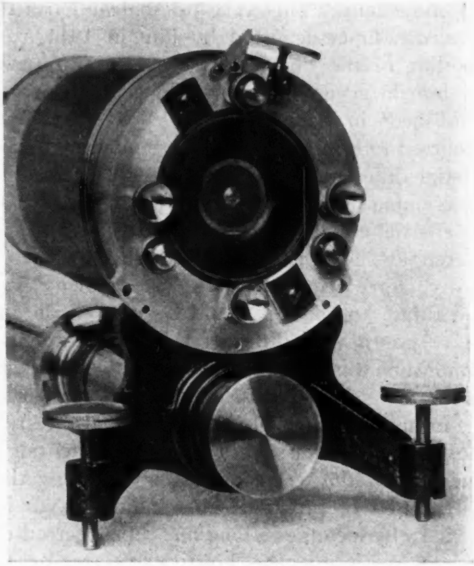


Webster's drop chronograph.

degrees of accomplishment, a first success, a persistent quest, and a last success.

Webster's *first success* was striking, for it won for him the Elihu Thomson prize of 5000 francs, in Paris, in competition with such well-known physicists of the time as Oliver Lodge and R. T. Glazebrook. The work was really finished and written up in 1893, but it was not submitted for the prize and published until 1898.[1] The subject of it was an experimental test of the formula for the period of an oscillating discharge of a condenser, which was, at that distant time, a very live subject. A carefully constructed air condenser, the capacitance of which was calculated, was started discharging through a coil, the inductance of which was also calculated, and the potential difference of the plates was determined at the beginning of the discharge and at very short intervals later. This involved the use of a quadrant electrometer in an ingenious way and a "drop chronograph," a novel device, for determining the intervals. Even this bare outline will show that the work called for very careful design of apparatus, very good workmanship, and a high degree of skill in making the measurements and the necessary corrections. The test consisted essentially in finding whether the substitution of the measured quantities in the theoretical formula gave the correct value for v, the ratio of the electromagnetic unit of quantity to the electrostatic. It was found that it did and this confirmed an important part of electromagnetic theory.

What I have called a *persistent quest* consisted of a series of efforts between 1897 (or earlier) and 1919 (or later) to perfect a portable phonometer, or apparatus for making "absolute" measurements of sound intensity; that is to say, measurements which would not call for the transformation of acoustic energy into electric or other forms of energy. Such an apparatus, properly described and specified, could be reproduced at any time or place and comparable measurements made. But designing and constructing an instrument of adequate sensitivity was no light task. The variations of pressure when a man is speaking in a loud voice are only a few millionths of atmospheric pressure, and it would take ten million cornets, playing *fortissimo*, to emit energy



Webster's absolute phonometer.

of sound at the rate of a horsepower. In its final form, as described and used at a meeting of the Royal Institution of Great Britain,[2] Webster's phonometer consists of a resonating tube, open to the sound at one end with the other end closed by a resonating membrane (double resonance), the movements of the membrance being transmitted to a light steel torsion strip that carries a small concave mirror. Light from a straight-filament lamp falls on the mirror and is focused on a scale, the amplification being between 1200 and 1500. The instrument is calibrated in light waves by means of a Michelson interferometer, with the membrane serving as one of the plates. Replicas of it have been used at the Riverbank laboratories, under P. E. Sabine, for studies in architectural acoustics; and at Farther Point, Quebec, for the measurement of fog signals. It is so ingenious and well designed that it is too early to say it will not be found a useful instrument in the future.

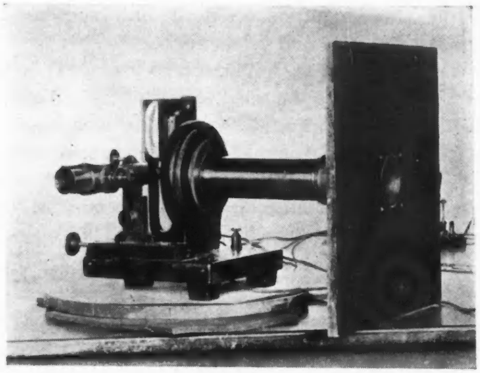
Webster's *last success*, as I have called it, was the suggestion and working out of an analogy between acoustic and electric phenomena and the introduction of the very important concept of an *acoustic impedance*, corresponding to elec-

[1] Phys. Rev. 6, 297 (1898).

[2] Proc. Nat. Acad. Sci. 5, 173 (1919).

tric impedance. This very original and fruitful idea was first suggested by him in 1914 at a meeting of the Physical Society and was used by him in acoustic investigations, but was not published[3] in detail until 1919. I suppose it occurred to him because of the similarity of the partial differential equation he derived for the functioning of a phonograph horn to the partial differential equation for the current produced in a complex network by an alternating electromotive force. But suggesting the analogy was one thing, to show it could be worked out in detail was a very different thing. Webster accomplished this by skillful mathematical analysis for the case of a horn of longitudinal section in the form of an exponential curve. He also tested the performance of such a horn experimentally. One part of the test consisted in exploring the distribution of pressures in standing waves in the horn by means of a long fine tube inserted to various points in the horn (somewhat as a physician gets samples of the contents of a stomach). The standing waves were produced by Webster's standard phone (a standardized tuning fork and resonator) as source of sound, and the measurements of pressure (relative) were made by means of his phonometer at the other end of the tube. Observations and calculation from the theory were found to be in satisfactory agreement. A by-product of the work was a proof that the characteristic tone of a "brass" musical instrument is not due to the substance but is entirely a matter of geometry, as he showed by making a heavy plaster of paris casting of a brass trombone bell and showing that it had exactly the same tone as the brass bell. The concept of acoustic impedance has been developed extensively by others and found very useful in the design of apparatus, especially in the Bell Telephone Laboratories. Crandall of the Bell staff, in giving Webster credit for the concept of acoustic impedance, states that the paper in which it was introduced is now the starting point of horn theory generally; and Everitt, of Ohio State University, refers to it as one of the most powerful tools introduced since the time of Rayleigh.

The volume of the *Proceedings of the National Academy of Science* in which the article on acoustic impedance appeared[3] contained no fewer than six articles, theoretical and experimental, by Webster; the others being on such widely different subjects as his phonometer, the angle of repose of wet sand, tables of zonal spherical harmonics, equation of state of powder gases, and a new instrument for measuring pressures in a gun. As all of these were extended reports on original work and replete with details, and the next volume (1920) contained five papers on a similar variety of topics, Webster's scientific activity at that time, especially for a man who was beginning to despond, was certainly rather remarkable.



Webster's phone, or standard source of sound.

Two special groups of papers call for brief mention, as indicating, at least, the immense range of Webster's scientific activities. The first group consisted of several papers on what was pure mathematics rather than physics. As to their importance, I must confine myself to noting that they were accepted by, and published in the proceedings and bulletins of the American Mathematical Society, the National Academy of Science, the American Academy of Arts and Science, and the American Philosophical Society. The second special group of papers, written during the war, was on ballistics and consisted of contributions to the National Academy on the theory and practice of gunnery, some of them descriptive of new instruments and devices.[4] To what extent they have been of service to the army and navy, I do not know. Webster had hoped that the work would receive

[3] Proc. Nat. Acad. Sci. **5**, 275 (1919).

[4] Proc. Nat. Acad. Sci. **5**, 259 (1919); **6**, 648 (1920).

official support and lead to a course on ballistics under his direction; but, while the importance of the work was acknowledged and his qualifications for it admitted, the hope was not fulfilled, much to his disappointment.

To the new developments in physics which were well under way in the later part of Webster's life, he made apparently no attempt to contribute, though he kept well-informed about them and expounded some of them in his lectures. J. C. Hubbard, professor of physics, Johns Hopkins University, one of his students, states that Webster was one of the first in this country to lecture on quantum theory, on electron theory, and on relativity. Yet he did not feel at home in this new work, so different from the classical physics in which he had been trained and which stopped at the impenetrable atom of the nineteenth century. What might be called the explosion of the atom early in the twentieth century changed all that and let loose a flood of new discoveries and novel concepts, which did not appeal to Webster as the old physics of a continuum had. I am inclined to think that if he had lived two or three years longer, until deBroglie startled physicists (in 1924) with the daring theory that matter, like light, has an intrinsic wave nature and especially until Schrodinger (in 1926) published his fundamental partial differential equation of wave mechanics, Webster might have found an interesting and congenial field for further work, one in which his special mathematical gifts and tastes would have fitted him well for valuable service.

In considering the assistance Webster gave to the progress of physics in America, one very definite service must not be overlooked. In Europe he had observed the great usefulness of scientific societies in stimulating and coordinating the work of individuals. Here in America there was no national organization of physicists until 1899 when the American Physical Society was organized. As to the part Webster took in founding the society, those now living who were active in the work seem to be in agreement. Professor W. F. Magie, of Princeton University, one of the original members, states: "Webster showed at his best in his work in the American Physical Society, the organization of which was started by him and accomplished almost entirely by his efforts;" and similar statements have come from Professor A. G. McAdie, of Harvard and Emeritus Professor J. S. Ames, of Johns Hopkins. Professor McAdie adds:

> At meetings of the Physical Society and the American Academy, Webster was often on his feet, giving his views of the matter. He felt that he *ought* to speak and that he was giving us the judgment of an expert, for his knowledge, training and experience had been such as few of his co-workers could hope to have. There are those who thought he talked too much, yet no one could gainsay the fact that he was well worth hearing.

I have italicized the word "ought" in the quotation because I have no doubt as to the essential correctness of this explanation of the frequency with which Webster spoke in the Physical Society and elsewhere, though no one believes that in what we do we are usually actuated by single motives or instincts. It may be added, I believe that no one ever heard Webster claim special credit for the part he played in starting the Physical Society on its highly successful and useful career. In this connection, we are reminded in a certain way of Rowland's reply, on being asked how he could venture, when on a witness stand, to claim to be the leading physicist of the country: "But I was under oath." The presidents of the Physical Society in its first two years were Rowland and Michelson, men of high distinction, and Webster was its third president, which indicates the position that Webster held at that time among American physicists.

This brief sketch of Webster's scientific activities calls for some mention of the numerous occasions on which he was an officially appointed representative at conferences or congresses in Europe and in this country. Such gatherings are often of very great service as aids to the progress of science in the world. The following is only a partial list of Webster's activities in this field. In 1910 he was the representative of Clark University at the one hundredth anniversary of the founding of the University of Berlin. In 1912 he represented the United States government at the radiotelegraphic conference in London, where he was the spokesman of the American delegation because of his fluency in the French language. In 1915 he represented the American Mathematical Society at conferences on aeronautics in New

York. A *physicist* representing a *mathematical* society at an *aeronautical* conference must have been, it will be admitted, a man of very remarkable accomplishments. In 1917 he was appointed by the Secretary of the Navy as a member of the Naval Consulting Board and served until the Board was disbanded after the war. His mission to France in 1919 will be referred to later. The mere enumeration of these activities, without any account of the detailed work involved, in which Webster always took an active part, shows, in a striking way, the width of his interests.

It might be thought that such immensely varied activities as have been referred to, combined with arduous teaching without leave of absence at any time, would have been a sufficient tax on the time and strength of any man. But in Webster's case it was not so. Throughout his career he kept writing voluminously in magazines and to weekly and daily newspapers on a great variety of subjects. These articles and letters were sometimes hasty and unguarded, and, though inspired, I believe, chiefly by a desire to be of as much service in the world as possible, they were attributed by many to a mere desire for publicity, which they certainly were not. It is to be questioned, however, whether they were of any service comparable with the time and energy spent on them. The hastiness and lack of careful thought shown in some of them were very unlike the habitual painstaking care of Webster's experimental work and his self-restraint in sometimes postponing its publication for an unusual length of time. It was inevitable that these inconsistencies should be a source of much misunderstanding.

His Versatility

Webster was a man of very exceptional versatility, and as this natural endowment played an important part in his life, it is necessary to realize its extent. His primary interests were, of course, those of a physicist, especially a mathematical physicist. For success in his professional work the physicist needs to know enough of certain foreign languages, especially French and German, to be able to read books and periodicals written in those languages. But to read a foreign language is one thing, to speak it and to understand it when spoken is an entirely different thing. In Webster's case a natural gift for readily acquiring command of a foreign language, as regards both reading and conversation, appeared early in his career. In fact, even in his senior year at Harvard he was, for some time, in doubt as to a choice between philology and science for his future work. What decided him in favor of science and especially physical science, I do not know. It was the feeling of his fellow students at college that "Webster could take any prize that he wanted," and this, no doubt, implied a belief that he might be expected to achieve success in almost any line that he might select. It may not be amiss to remark that the bases on which such choices are made are often very inadequate, and it is to be hoped that some scientific method may be devised for assisting in such choices of a career.

His four years of study in Berlin gave Webster a full command of the German language. Sandwiched in his semesters there, were many weeks spent at the Universities of Paris and Stockholm, and travels in Italy, Austria, Denmark, and Sweden, in each of which, in his own words, he "devoted a good deal of attention to languages." His command of French was such that in 1919 he was appointed by the French Institute in the United States a member of the "Mission de Rapprochement" to France. In this capacity he traveled widely in France, visiting most of the universities and stirring great enthusiasm by numerous extemporaneous addresses in French. On the same occasion he also lectured at the Sorbonne on his acoustical researches.

In addition to reading and speaking German, French, and Swedish fluently, Webster had a good reading knowledge of Italian and Spanish; and in the last months of his life he was giving more or less attention to Russian. Even modern Greek did not escape his omnivorous taste for languages. A society of Greek immigrants in Southbridge near Worcester invited him to be present and speak to them, and, to their surprise, he delivered a lengthy address in which modern Greek, the pronunciation of which he had taken pains to acquire, alternated with English. The same address was delivered later in Faneuil Hall in Boston and on other occasions. In this effort he was more successful than the great English statesman, Gladstone, a proficient in

ancient Greek, who once delivered to an enthusiastic audience in Athens a lengthy address in ancient Greek, pronounced in the Oxford way, only to learn weeks later that his audience thought he was speaking eloquently in English. In the course of his visit to Paris in 1919 Webster gave, in behalf of the Greek society in America, a dinner to which the eminent Greek statesman, Venizelos, and his staff were invited and addressed them in modern Greek. Venizelos returned the compliment by a dinner and also invited Webster to visit him at some later date in Athens and speak to the Athenians; but no fitting opportunity presented itself and the visit was never paid, much to Webster's regret. We can only imagine the pleasure it would have given him to address the Athenians from some rostrum where Demosthenes and Aeschines might, perchance, have spoken.

Somewhat allied, I suppose, to the mimetic element in a capacity for acquiring languages is the possession of dramatic instincts and dramatic delivery. With these, Webster was exceptionally well endowed. As a raconteur among his friends and as a reader of a great variety of parts in Shakespearean plays, he was so effective and intelligent that many thought he might have had a notable career as an actor. His striking presence and powerful but well-modulated voice would have contributed greatly toward it.

As a forcible and fluent speaker on a variety of topics, Webster was in great demand for commencement addresses at various American colleges. At meetings of scientific societies he never failed, when present, to play a leading and often highly stimulating part, not merely in America, but, which is a little more surprising, in Europe as well. Sir J. J. Thomson, the eminent English physicist, said of him: "The characteristics that I recall most vividly are the wideness of his knowledge and his power of vivid and graphic expression;" and he adds: "A debate rarely dragged if Webster were one of the audience." In the same connection, another Englishman, O. W. Richardson, of King's College, London, said of him: "Any scientific gathering that secured his presence was assured of success."

Another well-known physicist who admired Webster's talents played the leading part in a somewhat amusing incident that I may, perhaps, be permitted to relate, though I figure in it myself. At one of the early meetings of the Physical Society I had read a slight paper on some measurements in sound, and in the intermission or afterwards I was standing listening respectfully to some discussion by Webster, whose principal experimental work was in sound, and Professor Sabine, of Harvard, founder of the subject of architectural acoustics. Just then a cheerful, beaming young man, with nothing of the air of a great scientist, strolled up and remarked smilingly: "Methinks I see before me three *sound* men!" The speaker, of charming manner but modest wit, was at that time a professor in McGill University, but was better known afterwards as Lord Rutherford, of Cambridge University. On another occasion, when I chanced to be sitting beside Rutherford, and Webster had been speaking, he remarked: "Webster's a great fellow, I like to hear him speak." In later years Rutherford was always interested in hearing about Webster from transatlantic visitors to Cambridge, for he had a warm feeling of friendship for Webster, whom he had visited in Worcester before going back to England.

The three men with whose names I have for a moment ventured to associate my own have now, alas, passed on. Perhaps I may add that Rutherford's British fellow-physicists have often been men with a high (natural or cultivated) sense of humor. Maxwell wrote humorous poetry with great fertility of whimsical ideas and high technical finish and with remarkable facility. Older physicists will probably remember his rhyming report of a popular lecture by Tait at a meeting of the British Association for the Advancement of Science, "Ye *British Asses*, who expect to hear Ever some new thing. . . ." and his account in verse of Rowland's experiment, "Rowland of Troy, that doughty knight. . . ." Kelvin was an inveterate humorist in the pawky Scotch style, especially when teasing his massive friend Tait, who was witty in his own rather sardonic way and kept up a rhyming correspondence with Maxwell on physics for many years. Psychologists tell us that a sense of humor, even one deliberately cultivated, may be invaluable in preserving mental health. Though Webster had a clever wit, among his many gifts

a sense of humor, natural or cultivated, was unfortunately not prominent. I would venture to recommend a consideration of the subject to any younger physicist who finds himself at any time inclined to despondency.

With such gifts for public speaking and with a real zeal for doing everything in his power to advance good causes, it is not surprising that Webster was sometimes tempted to enter the political field. On one occasion he did, indeed, make an effort to enter local politics but was not successful, and the attempt was not repeated. This failure can hardly be regarded as unfortunate, for, with his habit of unrestrained utterance regardless of circumstances and consequences, it is highly probable that he would have found political life of any kind an unhappy and disappointing experience.

His Personality

To write, except superficially, of the personal characteristics of an ordinary man is difficult for anyone except a psychologist or a literary artist. The task is still more difficult in the case of such a bafflingly complex personality as that of the subject of the present sketch. In the following few notes I have thought it highly desirable to depend chiefly on the evidence of more competent witnesses, rather than on my own imperfect powers of observation and expression.

Webster's position in the ranks of the American physicists of his time is not readily stated in the terms that we usually employ for such purposes. In certain ways he was not merely one of the leaders but was the most prominent. The great extent and variety of his interests and his numerous appearances in public here and abroad gave him, I suppose, a position among intelligent people and the reading public not equalled by any of his contemporaries. Among his fellow physicists he was regarded, chiefly because of his books, as a leading authority on mathematical physics. In the field of experimental physics and research, in spite of his extensive contributions to acoustics, electromagnetism, and ballistics, Webster was much less successful. His mind did not seem to turn instinctively to widening the horizon of knowledge, partly, perhaps, because of his intense preoccupation for so many years with formulating, coordinating, and expounding the work of his great predecessors. This cannot, however, be regarded as the full explanation. His eminent contemporary and close friend, Professor Ames, was, I am told, accustomed to exhort his research students to "seize with avidity the moment of excited curiosity." To Webster, as, with his characteristic honesty, he freely admitted to his friends, these precious moments did not come with the frequency and vividness that he would have desired. Whether the result would have been different if he had not been endowed by Nature with so many diverse gifts and had not, in consequence, had so many distracting activities and subconscious preoccupations, it is perhaps futile to inquire.

One marked characteristic of Webster's personality—his intellectual honesty and frankness—has already been referred to and deserves to be emphasized, though it is not a quality that always brings unmixed happiness to the possessor. In this connection I am permitted to quote the statement of Webster's colleague, W. H. Burnham, emeritus professor of education and school hygiene in Clark University and author of *The Wholesome Personality* and other books.

> In a world burdened with convention, where words are often used to conceal thought and silence is often a mask for unkind attitudes or childish emotions, it was as refreshing as an ocean breeze to listen to Webster's naively frank expression of his thoughts and feelings. What to his acquaintances often seemed brusqueness and unjustifiable frankness was, in part, precisely what endeared him to his friends. On any subject, however personal to the hearer, he gave his own opinion directly and without camouflage or evasion, praising and blaming with equal emphasis and whole-heartedness.

President Stanley Hall, who called him to Clark University and with whom Webster did not always agree, said of him: "I never knew anyone who both thought and spoke so straight, and that on all matters, as Webster." And Professor Magie said with equal terseness: "He was one of the most warm-hearted and one of the most candid and upright in his thinking that I have ever known." To this I may add the testimony of Edmund C. Sanford, late professor of psy-

chology in Clark University: "No suspicion of craft, of double-dealing or of selfishness ever clouded our thoughts of him. He was always the same—strong, friendly and four-square." With these words of hearty admiration of his friends I agree fully; but, as a conscientious historian, I feel compelled to add that Webster did not always pause to reflect that silence may also be golden where speech can serve no good purpose and is therefore liable to produce misunderstanding. Yet there was a quality of naive sincerity about his occasional impulsive speech that, while it did not always prevent temporary resentment, did usually avert anything like permanent hostility.

Closely allied to Webster's intellectual honesty was his modesty regarding his status and achievements. This, as so often happens in such cases, was an attitude only well known to his close friends. Pupin, who was perhaps closer to him in spirit than any other physicist, said of him: "When he spoke of himself, he always dwelt—alas, too much,—upon his alleged shortcomings. He seldom referred to his successes, but he never hesitated to point out his failures." Other evidence to the same effect might be quoted. In my own conversations with him, he alluded, not infrequently, to his defects as a physicist, as he regarded them, and especially regretted that he had not been granted more of the gift of originality. When, however, we turn from the testimony of those who knew him best to the impressions of those who knew him only as an aggressive talker in social groups or as a dashing public speaker and lecturer, it cannot be denied that the picture is very different. Perhaps all men who are led by their natural gifts to play a variety of roles on the stage of life are accustomed to assume the masks that seem appropriate to the parts. The president of the United States who, by his laconic public speech, earned the soubriquet of "the silent" was, I have been told on good authority, a very fluent talker in private intercourse. Those who saw Webster only in public or in social relations and found him a somewhat flamboyant and self-assertive personality would probably have been astonished if they had followed him into his lecture room and seen the outer garment of dogmatic aggressiveness fall from him as he settled down to the quiet earnest work of the modest truth-seeking teacher. That this apparent contradiction existed in Webster's personality, as it has in those of many other gifted men, is evident; but it is no part of my duty as a mere narrator to attempt to explain it in the terms of modern psychology.

Certain minor, though very interesting, traits of Webster's character have been touched on so felicitously by the late Louis N. Wilson, the highly esteemed librarian of Clark University, who knew him intimately and talked with him almost daily for thirty years, that I cannot do better than make use of Mr. Wilson's account here.

> He was not a man who had playful moods. He had no patience at all with the commonplace and the vulgar, and he did not hesitate to express his contempt for such things. I sometimes think that it might have been a good thing for him if he had indulged in some of the minor vices of men. If he had been lazy occasionally, if he had smoked or enjoyed a little gossip, it might have helped out. But he brushed all these things aside as non-essential, hated smoking, and it was impossible to gossip in his presence, as he simply would not tolerate it, even in its most harmless form. Every waking hour seemed to be filled with an intense earnestness, and he would pass from one subject to another, carrying into the new subject just the same vigor he had expended upon the old. The mispronunciation of a word would send him to the dictionary, and he would not rest content until he had decided whether his pronunciation was correct or that of the speaker. It was characteristic of him that whatever he did was done with great thoroughness.

It should be noted, however, that he did learn to play golf, though he never played it well, master of the principles of dynamics as he was. But I do not think he went as far as my old teacher, P. G. Tait, also a master of dynamics, who, I believe, thought golf to be just a little more important than "Natural Philosophy," as the Scotch called physics. To Mr. Wilson's notes, it should perhaps be added that Webster's intolerance of mediocrity in the form of popular mistakes in science and even of grammatical errors sometimes found expression in public print. Being somewhat unguarded, such comments were often taken as mere conceit of knowledge and gained for the writer a wholly undeserved reputation of being hypercritical.

One other characteristic of Webster's that deserves special mention was his hearty, outspoken admiration for whatever he found admirable in the work of others, and especially in the work of younger men who might need encouragement. Here again, I cannot do better than quote from Mr. Wilson:

> In his personal relations with his friends Webster was especially charming. He could remember more kind things about them than anyone I ever knew. There was no professional jealousy in his disposition. He delighted to write of his colleagues in a laudatory way, and he delighted to talk of them in the same manner.

Another who knew Webster well, Professor Henry Crew, of Northwestern University, wrote:

> Nothing can ever dull the edge of my memory concerning Webster's boundless energy . . . , the breadth and fairness of his view. Here in the Mississippi Valley he is missed by hundreds of friends who have derived inspiration from his discussions. These friends can never forget that rich sonorous voice, raised sometimes in clear exposition of the truth, sometimes in defence of fair play, often in congratulation of some new or young man to whom such approval was encouraging beyond measure.

And his colleague, Professor Burnham, has this to say:

> As a result of acquaintance with Dr. Webster for over thirty years as a colleague and intimate association with him in some of his work, the impression I formed of him was, not only of his great scientific ability and remarkable scholarship, but especially of his honesty and sincerity of thought, his hearty appreciation of the work and ability of others, his sympathetic attitude, and the refreshing stimulus of his open-mindedness.

If it be remembered that the generous and wholly spontaneous commendation of the work of others referred to in these last statements came from one who regarded himself as having failed, it will, I think, be admitted that, though he perhaps did not use his very great gifts in the wisest way and made serious mistakes in the conduct of his life, Webster had an essential nobility of character that allied him closely to the truly great men of science of all time.

It will be unnecessary to dwell on the feeling of defeat and discouragement that oppressed Webster in the last few years of his life or to seek its explanation in the complexities of his very unusual personality and its reactions to what may, in a general way, be called external circumstances. The account may, I think, be closed most fittingly by a quotation from one who loved him deeply, esteemed him highly, and understood him better than anyone else, his colleague, Professor Burnham. "On the evening before the fatal day Dr. Webster suggested to me that we walk home together. In this last conversation with him, he showed his usual clarity of judgment, his sympathetic attitude, and especially his depression. The walk was all too short, but the impending tragedy was never suspected; so little are the frankest men thoroughly understood even by their friends."

The Pennsylvania Conference of College Physics Teachers

THE annual fall meeting of the Pennsylvania Conference of College Physics Teachers will be held at the Pennsylvania State College on October 14–15. On Friday afternoon there will be two parallel sessions, one devoted to contributed papers, the other to a program for physics students, sponsored by the local chapter of Sigma Pi Sigma. After the dinner on Friday evening, David Dietz, Science Editor of the Scripps Howard publications, will address the Conference on the subject, "The Cultural Values of Physics." The Saturday morning session will be a symposium by five college presidents on the subject, "Physics as an Essential Part of a College Education." The participating presidents are J. A. Schaeffer, Franklin and Marshall College; P. S. Havens, Wilson College; P. R. Kolbe, Drexel Institute of Technology; C. S. Swope, Westchester State Teachers College; and T. J. Higgins, St. Joseph's College. They will represent, respectively, the points of view of an endowed liberal arts college for men, an endowed liberal arts college for women, a technical college, a state teachers college, and a Roman Catholic college.

All who wish to contribute papers to the session on Friday afternoon should send the titles to Professor T. D. Cope, Department of Physics, University of Pennsylvania, before September 15.

Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics

E. C. WATSON
California Institute of Technology, Pasadena, California

2. Prints of Early Mechanical Road Vehicles

THE first practical mechanical road vehicle was the steam tractor built in 1769 by NICHOLAS JOSEPH CUGNOT, a French military engineer (1725–1804). It attained a speed of just over two miles per hour on a level road, but the boiler capacity was sufficient only for twelve or fifteen minutes of running. By order of the French government, a second tractor was constructed in 1770 for the transportation of artillery, but it was never used. It is now preserved in the Conservatoire National des Arts et Métiers in Paris, where the photograph was taken from which Fig. 1 was made. The following description appears in the *Catalogue* of the collections in the Science Museum, London, where a small scale model is displayed:

> It consists of a heavy timber frame supported on three wheels and carrying in front an overhanging copper boiler. The front wheel has a broad, roughened tyre, and is driven by two single-acting inverted vertical cylinders 13 in. diam. by 13 in. stroke. The two pistons are connected by a rocking beam, and their motion is transmitted to the driving axle by pawls acting on two modified and reversible ratchet wheels. The distribution of steam to the two cylinders is performed by a four-way cock actuated by a tappet motion. A seat is provided for the driver, who, by means of gearing, was able to steer the machine, the boiler and engines turning together as a fore-carriage through 15 deg. either way.

The first mechanical road vehicle to make a journey of any length was the steam carriage built in England by SIR GOLDSWORTHY GURNEY (1793–1875). The description beneath the print in Fig. 2 reads as follows:

> The Guide or Engineer is seated in front, having a lever rod from the two guide wheels to turn & direct the Carriage & another at his right hand connecting with the main Steam Pipe by which he regulates the motion of the Vehicle—the hind part of the Coach contains the machinery for producing the Steam, on a novel & secure principle, which is conveyed by Pipes to the Cylinders beneath & by its action on the hind wheels sets the Carriage in motion—The Tank which contains about 60 Gallons of water is placed under the body of the Coach & its full length and breadth—the Chimneys are fixed at the top of the hind boot & as Coke is used for fuel, there will be no smoke while any hot or rarified air produced will be dispelled by the action of the Vehicle—At different stations on a journey the Coach receives fresh supplies of fuel & water—the full length of the Carriage is from 15 to 20 feet & its weight about 2 Tons—The rate of travelling is intended to be from 8 to 10 miles per hour—The present Steam Carriage carries 6 inside & 12 outside Passengers—the front Boot contains the Luggage.

Although planned for regular service between London and Bath, the coach of GURNEY remained in an experimental state. Its chief performances were the climbing of Highgate Hill on June 14, 1828, thus demonstrating the possibilities of steam in climbing a prolonged slope, and the trip from London to Bath in 1829, the first trip of any length to be made by an automobile. Nevertheless it was not successful technically, partly because the mechanism was inaccessible and badly protected.

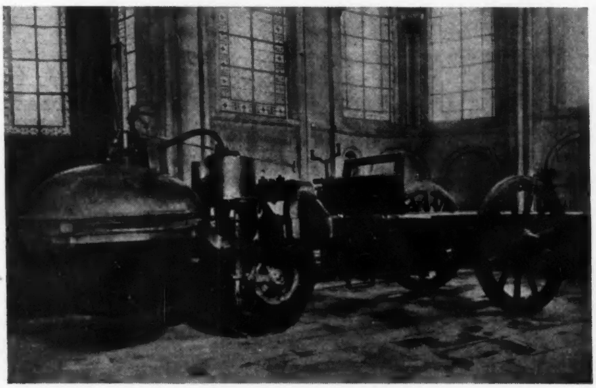


FIG. 1. CUGNOT's steam tractor (1769–1770), the first practical horseless road vehicle.

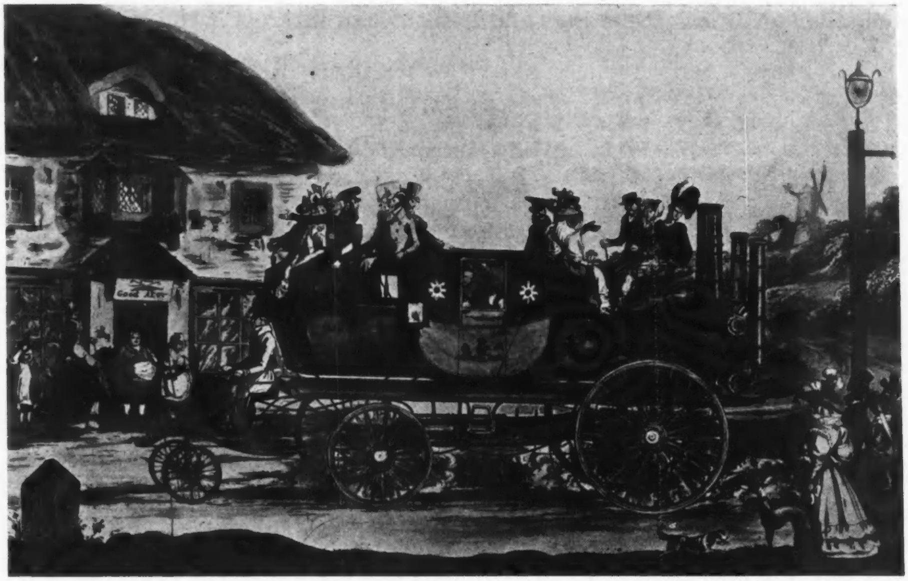


FIG. 2. GURNEY's steam carriage (1827–1829), the first horseless carriage to make a long journey. (From a magnificent colored aquatint, 9.5×15 in., by G. Morton and Pyall.)

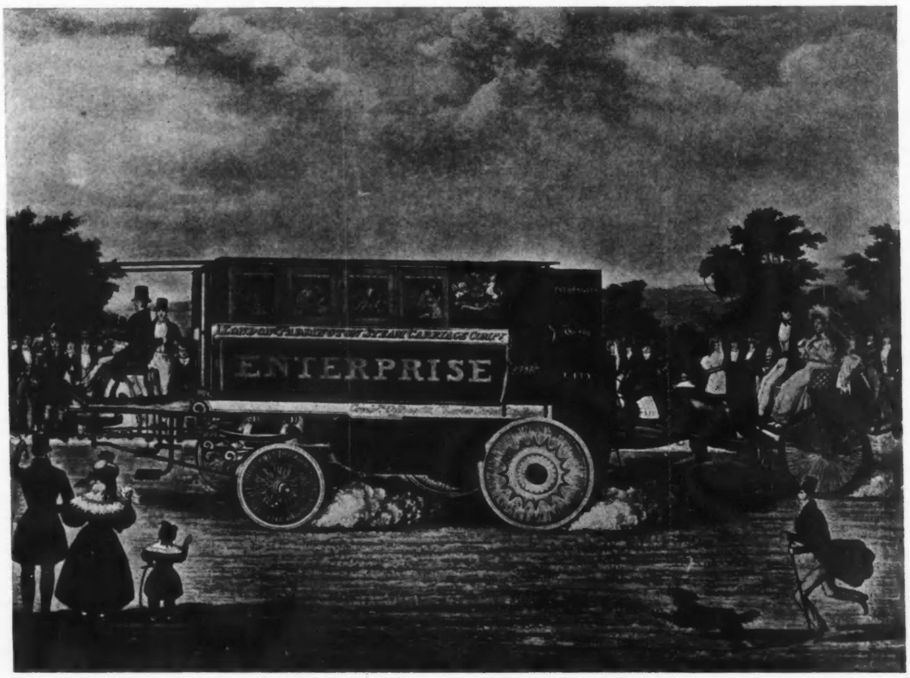


FIG. 3. HANCOCK's steam omnibus (1833), the first omnibus in regular service. (From an aquatint by W. Summers and C. Hunt.)

Between 1827 and 1838 WALTER HANCOCK (1799–1852) of Stratford, England, built nine steam carriages of various types, all of which were mechanically successful. On April 22, 1833, one of these, named the *Enterprise* (Fig. 3), was put into regular service between London and Paddington. This was the first mechanical vehicle especially built as an omnibus to be put into continuous service. Being more novel than the horse-drawn coaches, it was favorably received by the public.

FIG. 4. CHURCH's ornamental three-wheeled steam coach (1833). (From an engraving by John Cooke and Josiah Allen.)

Figure 4 shows a curious coach built in 1833 by WILLIAM CHURCH. This coach, which ran for a time between London and Birmingham, had wheels with flexible spokes and very broad but elastic rims.

Further details of early road vehicles and their history will be found in the *Histoire de la Locomotion Terrestre*, by CHARLES DOLLFUS (*L'Illustration*, Paris, 1936) and in the *Catalogue of the Collections in the Science Museum, South Kensington, with Descriptive and Historical Notes and Illustrations. Land Transport. II. Mechanical Road Vehicles* (London, 1925), from which much of the foregoing discussion was taken.

Some Economic Aspects of Physics[1]

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THE physicist, as I have known him over a quarter of a century, is essentially a conscientious individualist. A combination of thinker and craftsman, he finds his principal pleasure in his work itself, and his principal reward in its approbation by a small group of his profession rather than in the economic dividends which result from it.

Yet, all too often, this individualist is either too busy or too indifferent to consider the value of organization in his profession, and to reflect on some of the broader aspects that vitally affect the future of his profession.

The leaders in the profession have not been unaware of this; various societies have been formed, and various journals launched, to integrate the several activities of this individualist. To mention a few, the American Physical Society has for years effectively stimulated physical research; the American Association of Physics Teachers has worked valiantly for the recognition of physics as a profession and for the dignity of the art of physics teaching at the college and university levels; applied physics has been openly recognized by the creation of a separate journal; our own Southeastern Section of the American Physical Society brings professional matters nearer home to many of us; and finally, the belief in the desirability of a holding company

[1] Read at the annual meeting of the Southeastern Section of the American Physical Society, Tuscaloosa, Alabama, April 1, 1938.

to coordinate all the different activities of physicists led to the formation, in 1931, of the American Institute of Physics, whose past achievements and future potentialities command our unqualified support and interest.

Yet, in spite of all that has been done, it is my feeling that the average physicist has remained essentially an isolated individualist who assumes that he is still working in a laissez-faire situation, who allows his contributions to be absorbed under other professional labels, who is still somewhat impatient with organization, and who is inclined to discount some of the broader aspects which may profoundly affect the future of his profession.

This paper deals briefly with three of these broader problems of the profession.

The first problem I call the "youth problem" in physics. In the report of the Committee on the Present Status and Tendencies of Physics in Secondary Schools of the South, prepared by C. R. Fountain, there appears a comparison by states of the status of secondary school physics for 1927 and 1934. Table I, which is an excerpt from this report, shows a decrease in secondary school enrolment in physics which should cause serious reflection. Please do not misunderstand me. I do not hold a brief for mere numbers, provided that in those numbers we find every potential physicist who might normally be expected to form the group, and provided also that the best minds who normally would join the group have not been unduly and artificially diverted into other fields.

TABLE I. *Science enrolments in Louisiana and Mississippi* (*Fountain*).

State	Year	No. of Schools	Enrolment	Give Physics		Take Physics		Give Chem.		Take Chem.		Give Biology		Take Biology		Give Gen. Sci.		Take Gen. Sci.	
				No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
La.	1927	209	29,057	49	23.4	1394	4.80	148	70.8	3711	12.8	151	72.2	5274	18.1	179	85.6	7,712	25.5
	1934	237	46,505	33	13.9	927	1.99	162	68.4	4661	10.0	189	79.8	7220	15.5	200	84.3	11,341	24.4
Miss.	1927	260	19,375	53	20.4	826	4.18	33	12.7	643	5.3	119	45.7	2238	11.3	172	66.2	4,114	20.8
	1934	287	30,935	37	12.9	613	1.98	96	33.5	1741	5.6	222	77.4	5358	17.3	208	72.5	6,121	19.8

My own studies since 1914 lead me to disagree with those who assert, or imply, that a secondary school course in physics is a liability or even an inconsequentiality for further study in college. A well-taught secondary school course, I find, is an asset. Hence I cannot dispose of the findings of Professor Fountain's committee by ignoring them as of no consequence.

For me there remains the question, why has secondary school physics failed to maintain its position in comparison with other sciences? These, perhaps, are some of the reasons:

(1) Physics laboratories are more expensive to equip than those of competing sciences; school administrations, thinking in terms of budgets, may look more favorably toward a less expensive alternate which will meet the science requirement.

(2) The vocational counselor may be unduly advising students to study other sciences. I am reliably informed that vocational counselors regard physics as an extremely difficult subject, and, unless a student has shown considerable success in mathematics, he is not encouraged to take physics. Do we need to educate the vocational counselor?

(3) Parents in particular and the community in general are unable to distinguish between physics and the other sciences and engineering which are more publicized; hence the physics student is deprived of the excitant of parent and public interest in this subject.

(4) All too often, physics is taught as a side line by a teacher who has not had the special interest and training in the subject that engenders and communicates enthusiasm.

There may be other reasons, but certainly as far as physics is concerned, it seems to me that the profession is faced with a youth problem.

The second general problem I would invite you to consider is the professional employment problem in physics. A going concern must find a market for its product and this is true of the profession of physics. Our graduates must find placement in the economic structure. My attention was emphatically focused on this matter last year in connection with the recent inspection of engineering schools by the Engineering Council for Professional Development (E.C.P.D.). To some of us who have been interested in physics

in engineering education, the whole affair presented certain disquieting tendencies. Until recently some of the best personnel for graduate work in physics were the engineering students who have included in their engineering training enough special course work in physics to constitute a physics major. At the Indianapolis meeting of the American Association of Physics Teachers, the Committee on the Training of Physicists for Industry gave its approval essentially to this combination as undergraduate and graduate preparation for the applied physicist.[2]

On the other hand, several engineering schools, Michigan and Lehigh, for example, had set up in the engineering curriculum undergraduate courses in applied physics (physical engineering or engineering physics, if you prefer), which courses had already turned out a respectable body of alumni successful in industry. Last summer, at the Physics Conference of the Society for the Promotion of Engineering Education at Cambridge, Professor Bidwell reported that the E.C.P.D. had declined to accredit curriculums in engineering physics, and quoted from a letter of Karl T. Compton who was chairman of the Committee on Engineering Schools. President Compton was rather of the opinion that applied physics might have to look to the associated societies of the American Institute of Physics for economic protection.

At first sight this situation may seem unimportant, but closer study reveals two possibilities. First of all, the accrediting of engineering courses by the E.C.P.D. has for an ultimate objective a general licensing law for engineers. Should such a law be drawn up, undoubtedly one of the first requirements will be graduation from an accredited engineering course. How will this licensing of engineers affect the practice of "Applied Physics"? Another possible result of this E.C.P.D. inspection is that engineering curriculums may become more technical at the expense of pure science subjects. Some of us think we have already seen this result in curriculum changes recently made in certain institutions of the South. The time allowed for physics instruction has been particularly vulnerable. Physics is being replaced by technical courses taught by the engineering faculty under such titles as "Elements of Electrical Engineering," or something similar. There is no doubt in my own mind that here is a potential intra-competition which may remove some of our best potential personnel for physicists and may embarrass the legitimate practice of the profession of physics in a consulting or other nonteaching full-time industrial employment. Other phases of this problem of professional employment might be raised, but perhaps these remarks will suffice to bring the matter to your attention.

Now we come to our last general problem, that of "Public Relations in Physics." In the last analysis, every professional activity must be financed, and this is also true of physics. Those physicists who are absorbed by large corporations often reappear classified as research engineers. Obviously, the financial support for their researches comes from the industries that support them and profit by their efforts. But who will furnish the financial support for research in private and state institutions, for the maintenance of adequate teaching staff and equipment, for the training of a better personnel? In the end, the support comes from the public.

Let us not forget that the legislator who votes the "engineering licensing law" will be a member of this general public; the secondary school administrators now deciding for or against support for physics will be influenced as a part of this general public; the parent who advises his son or daughter in the choice of subjects in the curriculum is a part of this general public. The demand for a better trained physics teacher will rise or fall with the interest of the general public in the subject of physics. And last but perhaps of great future significance, the government subsidization or support for research in physics will undoubtedly be affected by the legislator's interest and appreciation of the science of physics.

Why should the physicist disregard his public relations problem? Why should he hold his light under a bushel with a sense of false modesty? Other groups have regarded this public opinion and public appraisement of their profession as highly important. Can the physicist any longer afford to allow his achievements to be absorbed under an anonymous label without loss of prestige and lack of financial support?

[2] Am. Phys. Teacher **6**, 82 (1938).

These then are the three major problems which I would have you consider:

1. The youth problem in physics.
2. The professional employment problem in physics.
3. The public relations problem in physics.

What can we do about them? Here are a few suggestions which come to my mind. Possibly you can supplement them with better ones.

(1) The American Institute of Physics has already begun to do something about some of these problems; the Institute should receive your whole-hearted support.

(2) In regard to the youth problem (i.e., the secondary school problem, although, before we are finished, we very likely will have to include the junior colleges as well), the physics departments in the universities could assist materially by offering courses designed expressly for teachers of physics in secondary schools and colleges. Let the profession transmit its own pedagogic art and science under its own control. Let university physics teachers of skill and enthusiasm send out secondary school teachers of physics who are both skillful and enthusiastic. This will be a great help.

(3) The American Association of Physics Teachers provides possibilities for assistance which have never been realized. Everyone recognizes the value of this society as a medium for evaluating and improving the teaching of physics at the collegiate level. That in itself is enough to merit its financial support from every physicist. So much for its national implications. My present interest is in the utilization of local chapters of the Association. The constitution of this society provides that ten members in a community may constitute themselves into a local chapter. Such local chapters could well serve as sponsors for local lectures in physics, public demonstrations, and awarding of prizes for excellence in physics in secondary schools. These local sections might also act as clearing houses for teaching problems, for encouraging adequate legislation, and for education and stimulation of school administrators. I leave the rest to your imagination.

(4) We might convince the national physical societies that they ought to help us locally by bringing into our communities conspicuous national lecturers in physics. As the chairman on Public Relations of the Southeastern Section, I have been much interested in this as well as in utilization for this purpose of some of the physicists of our own section. While nothing definite can be promised at this time, I know that this matter is receiving sympathetic consideration by the Governing Board of the American Institute of Physics.

In this connection, I should like to quote excerpts from the last annual report of the director of the American Institute of Physics, Dr. H. A. Barton. I wish you could read the entire report, but I confine myself to three quotations:

> The efforts of the organization to develop cooperation by physicists in their own interest and in the interest of their science and also to make physics better known and more generally applied have resulted in considerable progress in 1937.
>
> * * *
>
> I think we must recognize that a profession whose cooperative service annually costs over $100,000, whose combined income is probably more than $10,000,000 and which uses laboratories and equipment worth possibly $50,000,000 is a profession or branch of human activity that has grown to the point where the need of a secretarial office is not surprising.

In speaking of suggested directions for development of the policy and aims of the Institute, Doctor Barton has this to say:

> My third suggestion is more far-reaching and it contemplates work which could be best done in cooperation with the American Association of Physics Teachers. I refer to the grounding of school children in physics, their intermediate teaching and, where needed, their vocational guidance. We are all well aware that early physics teaching is almost always absent or unsatisfactory. We can learn much from the chemists and engineers, who give their problem of orientation and early education much attention. If we can do something to put physics and its economic importance in the minds of school children, much of our present struggle for recognition and support will become unnecessary in the future.

A Two-Year Program in General Physics

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THE number of students who elect courses in college physics is relatively small. The present writers contend that an important factor contributing to this situation, which results in many students never becoming familiar with the field, is the failure of most teachers to recognize the fact that general physics has outgrown the conventional one-year course. The subject matter has increased to such an extent that in our opinion, a substantial treatment of all of it in one year is beyond the reach of the average student in the beginning course and a popular survey is too superficial. We are, therefore, faced with a challenge which the department of physics at the University of Maine has attempted to answer with the following program.

This program consists, for a given student, of two successive courses: a general introductory one of college grade in the first year and an intermediate one in the second year. This is not a single two-year course, but a sequence that has certain advantages shown by experience to be very real. The first year's work may be taken by the student in one of two ways. The one is a substantial ten-semester-hour course consisting of two lectures, two recitations, and one two-hour laboratory per week. It is designed to give the student an introduction to the general subject with ample drill in problem work, in which he is trained to reason out solutions from fundamental considerations and thereby to develop powers of analysis. This course is a freshman requirement for engineering students and, although not primarily a part of the program under consideration, is open to other qualified students who wish the longer course.

The other course, the one which primarily concerns us here, is an eight-semester-hour course designed to meet the needs of liberal arts and premedical students. It is build about the same identical two lectures per week as the ten-hour course. This procedure incidentally economizes on staff, and at the same time expresses the belief of the writers that "physics is physics" and that there may be a difference in length but no essential difference in kind between so-called "liberal arts" and "engineering" physics. The chief difference lies in the interpretations and the degree of appreciation of the same material by the two groups. This shorter course has only one recitation in addition to a two-hour laboratory period per week. The laboratory for the two courses is essentially the same but with a more restricted choice of material for the shorter course.

The common lectures tend to keep the shorter course as nearly up to the same academic level as the difference in hours will permit. This point seems quite essential since the mathematical background and analytical attitude of the average liberal arts student does not usually measure up to that of the average engineering student, presenting a situation which might tend to weaken the shorter course if it were entirely separate. A natural spirit of competition between the two groups stimulates the arts students to attempt to make a showing comparable to that made by the students in the longer course, with the double result that a comparatively high standard is attained and real physics is taught.

Another feature of this shorter course is the fact that no single textbook is used. Reading assignments are made for each topic in one or more of 14 different standard textbooks, thus giving the student the advantage of various points of view. The university library cooperates by purchasing extra books in a fixed proportion to the registration in much the same manner as it does with the more conventional reading courses. Unity is achieved by the use of a supplementary printed outline which serves as a lecture syllabus and makes it unnecessary for the student to divide his attention between the lecturer and the task of taking notes. Needless to say, such a course is developed around the lectures, the recitations being interpreted as opportunities for small group discussions and short range questioning. One general objective of this whole plan is to make the student feel

that he is studying physics and not a particular textbook.

The second part of this program is a course in intermediate general physics in which the subject is again covered, but this time in a more analytical manner. The student upon entering the second year already has a bird's-eye view of the subject as a whole and is therefore in a much better position to appreciate the intermediate work. He also has a better grasp of mathematics beyond algebra, geometry, and trigonometry by this time and frequently exhibits an interest in learning uses for it while it is still fresh in his mind. Furthermore, only serious students take the second course, and for such only does an analytical presentation have any real and lasting value. This course follows the general lines of a recommendation previously made by one of the authors[1] when he described a successful second-year course in general physics for college transfer students at the Massachusetts Institute of Technology. It was then proposed that such a course might well be considered to supplement the conventional one-year college course, on the grounds that it could easily be introduced, without upsetting already existing curriculums, to accomplish in colleges what the Massachusetts Institute of Technology course accomplished with students transferring from these colleges to that institution. We feel we can now say that this proposal has actually proved to be practicable.

The brief reviews which precede the extensions of the various topics constitute an extremely valuable part of the program. It appears certain that many of the concepts and relationships acquired in the first survey of a subject as well organized as college physics require restudy by the student who wishes to make this material serve as the basis for future building along professional lines.[2] This course is conducted on a six-semester-hour basis with three informal lecture-recitation meetings per week. The calculus is used freely, although some students in the course are studying the calculus concurrently. For such students the physical applications seem to increase interest in the study of the mathematics, and considerable attention is given to the analytical solution of problems.

Along with this classroom course there is an intermediate laboratory course which the student is urged to take. Here the more difficult experiments in general physics are performed with an aim toward greater precision than can be expected in the freshman laboratory.

It is apparent that this whole program places considerable emphasis upon general physics. The authors believe that 14 to 16 semester hours is not too much time to devote to the general, as distinguished from the specialized, aspects of the subject. Otherwise the specialized courses, often called advanced courses, must be made rather elementary. After pursuing such a two-year program, a student should be adequately equipped to enter the advanced work with a real appreciation of the analytical technics, the nature, and the scope of the science as a whole.

It may also be pointed out that such a first course as the shorter one here described appears to have considerable appeal for the general arts student, possibly because the analytical treatment is necessarily limited in anticipation of the second course. Experience with this program suggests that, in our attempts to do a good job in one year, we may have been making our first courses too analytical to attract students, and that more can be accomplished in the long run by reserving such material for a second year with students who have been prepared for, instead of frightened away from, that really fascinating subject, general physics.

[1] C. E. Bennett, Am. Phys. Teacher **2**, 158 (1934).

[2] Lapp and his associates [Am. Phys. Teacher **6**, 98 (1938)] find evidence of much half-learning in the present conventional course. Such a course as here described tends to relieve this situation before advanced courses are undertaken.

Meeting of the Kentucky Chapter

THE Kentucky Chapter of the American Association of Physics Teachers convened with the Kentucky Education Association at the University of Louisville on April 15. The program consisted of an address by the president of the Chapter, A. D. Hummel, Eastern State Teachers College; a demonstration lecture on optics, by R. A. Loring, University of Louisville; and a symposium on the curriculum, participated in by Bruce V. Vance, of Kenwood Hill, Harold P. Adams, of Bryan Station High School, and Eunice Bone, of Madisonville High School.

A New Method of Measuring Wave Speeds

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The speed of a wave can be calculated from the well-known formula $v=\nu\lambda$. As frequency and length are quantities that can be measured with extreme accuracy, a comparable precision would be expected in the values obtainable for v. In the usual standing-wave and interference methods, adjustments are made by observing an intensity maximum or minimum. Unfortunately, the introduction of this extraneous magnitude, intensity, gives rise to the greatest sources of error. It has occurred to the writer that it is possible to eliminate entirely the measurement of any third quantity, such as intensity.

The method will be described by reference to one actual application, namely, a "howling telephone," assembled by using a Brown tunable telephone receiver for the driving unit of a loudspeaker horn and connecting it, as in a public address system, with a crystal microphone and amplifier. When the microphone is placed in front of the speaker a note is heard, the pitch of which can be varied over a range from about 1300 to 900 vib/sec by changing the distance between source and pickup. As the microphone is moved steadily away from the speaker along its axis, the pitch decreases continously from the upper to the lower limit of this range, jumps back suddenly to the upper limit, decreases again to the lower limit, jumps back to the upper limit again, and so on. If a standard tuning fork with a frequency ν near the middle of this range is vibrating nearby, beats can be heard, and the positions of the microphone at which zero beat occurs can be found very accurately. The distance between two such successive positions will be the wave-length λ corresponding to the standard frequency ν. The speed of sound v is then given by the formula $v=\nu\lambda$. The measurement of a third quantity such as intensity is thus entirely avoided.

To understand fully why the distance between two successive positions of the microphone which give the same frequency is exactly a wave-length, it is necessary to consider in some detail the mechanism of the sustained oscillator. The energy sustaining the vibrations of the speaker diaphragm is "fed back" to it by way of the sound waves and microphone, and the frequency will depend on the phase of this feedback. This control of the frequency by changing the phase of the sustaining force fed back has been explained[1] by considering the harmonic displacement of the diaphragm as a projection of the uniform circular motion of a particle on a diameter. Let us use the customary notation and consider the radius vector from the center of the circle to the particle as a complex quantity $r=ae^{i\omega t}$ in the complex plane. Then $\dot{r}=i\omega r$ and $\ddot{r}=-\omega^2 r$. If there is a dissipative force $-R\dot{r}=-i\omega Rr$, it will be 90° ahead of the elastic force $-sr$.

The force due to the feedback sustains the oscillations and must be a function periodic with r, say, $F(r)e^{i(\omega t+\phi)}$. If we put $\phi=90°+\theta$, then θ will be the angle between $F(r)$ and $i\omega Rr$. The steady state conditions are then

$$F(r)\sin\theta+sr=m\omega^2 r,$$
$$F(r)\cos\theta=\omega Rr;$$

therefore,

$$\tan\theta=m\omega^2-s/\omega R=\omega^2-\omega_0{}^2/(\omega R/m),$$

where $\omega_0(=(s/m)^{\frac{1}{2}})$ is the angular velocity of the radius vector in the case in which the sustaining force is just equal in magnitude and opposite in direction to the dissipative force. In this case $\theta=0$ and the diaphragm vibrates as if free and undamped, with the frequency $\nu_0=\omega_0/2\pi$. If θ is not zero, but positive or negative, the sustaining force will have a component aiding or opposing the elastic restoring force, thus raising or lowering the frequency to the value $\nu=\omega/2\pi$. In other words, as the microphone is moved away from the speaker, θ decreases, the frequency decreases, and the wave-length increases; and the reverse is true as the microphone is moved toward the speaker. But θ must be between $-90°$ and 90°, for,

[1] A. E. Kennelly, *Electrical Vibration Instruments*, Chap. 23.

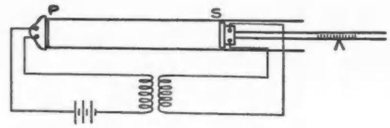

FIG. 1.

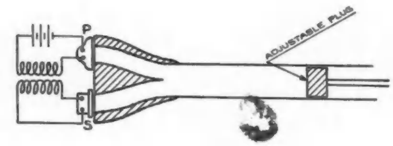

FIG. 2.

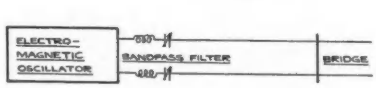

FIG. 3.

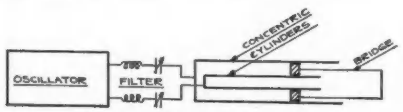

FIG. 4.

FIG. 1. Howling telephone for measuring sound speeds. FIG. 2. Apparatus modified to reduce end effects. FIG. 3. Analogous device for electromagnetic waves on Lecher wires. FIG. 4. Coaxial cylinders replacing Lecher wires.

if it were not, the force fed back would have no component opposing the dissipative force and the vibrations would cease or snap over to a different frequency. This explains the sudden jumps in pitch and the repetitions already mentioned. From the equation for $\tan\theta$ we see that the same frequency must recur whenever θ is the same, that is, whenever the microphone is at such a distance from the source as to intercept the sound at the same phase position. These successive positions are obviously a whole wave-length apart.

An idea of the sensitivity of adjustment of the apparatus for zero beat can be obtained by differentiation of the expression for $\tan\theta$ with respect to ν, which gives

$$\frac{d\theta}{2\pi}=\left\{\left(\frac{\cos^2\theta}{R/2m}\right)-\left(\frac{\sin 2\theta}{4\pi\nu}\right)\right\}d\nu.$$

An approximate value[2] for $R/2m$ is 500 and a change of frequency $d\nu$ of about 1 can be detected by ear using the zero beat method, so that $d\theta/2\pi$ is not more than about 1/500. This is consistent with the fact that the settings of the microphone can actually be found to about 0.1 percent of the wave-length.

[2] Reference 1, p. 300.

The apparatus already described should be used only when surrounded with absorbing material or when out of doors. However, a very simple device based on the same principle has been in use for some time in our undergraduate laboratory. The telephone receiver is fitted into a long brass tube so as to form a sliding plug, and an ordinary carbon microphone at one end serves as the pickup (Fig. 1). A telephone line consisting of battery and transformer completes the feedback system. A similar arrangement, usually with a fixed tube length, is used in telephone work as a method of testing receivers.[3] Apparently it has not been used for measuring wave speeds. One reason perhaps is that at first sight it appears to behave in a very complicated way, especially near the transition points where both frequencies sometimes are found at the same time. Measurements should not be made in this region. A delicate test of the uniformity of behavior of the apparatus was made by connecting a cathode-ray oscilloscope in the electric line so as to observe potential as a function of current. As the plug was withdrawn the ellipse passed through a series of contortions but always returned to the same form at the same frequency.

In Table I the viscosity correction was not considered. Judging from the consistency of the readings, the possible error is about 0.1 percent.

In the case of the closed tube, standing waves are produced by reflection at both ends; and, if the end effects are different functions of the number of wave-lengths present, a systematic error might arise. It does not seem to be apparent but the objection is met in the arrangement

TABLE I. *A typical set of data taken by a student.*

ZERO BEAT AT	DIFF.	
		Temperature of air, 21.2°C
18.64		
48.54	29.90	Barometer, 75.42 cm of Hg
78.43	29.89	
108.33	29.90	
138.21	29.88	
168.10	29.89	Frequency of standard fork, 1149.5±0.5 vib/sec (assuming usual precision for a standard)
Average 29.89±0.01 cm		

$v=\nu\lambda=1149.5\times 29.89=34359$, or $v=343.6\pm 0.3$ m/sec
$v_0=v/(1+at)^{\frac{1}{2}}=v/(1+21.2/273)^{\frac{1}{2}}=331.0\pm 0.4$ m/sec

[3] Bell System Tech. J. 5, 27 (1926).

shown in Fig. 2 where only a solid sliding plug is used.

The argument regarding sensitivity is also affected by the presence of standing waves, as it was assumed that the system had a fixed natural frequency ν_0 and this is not quite true when the resonant air column is changed by a small amount. The measurements show about the predicted sensitivity, however.

The effect of the standing waves on the strength and form of the sustaining force $F(r)$ does not introduce any uncertainty, as it was seen that $F(r)$ drops out of the equations, only the phase angle remaining. A strong feedback produces a large amplitude only.

The method is well adapted to measuring the speed of electromagnetic waves on Lecher wires or in coaxial tubes as shown in Figs. 3 and 4. In the electrical case the quantity corresponding to $R/2m$, namely $R/2L$, is as a rule larger, so that the loss of sensitivity due to changes in the angle θ is even less.

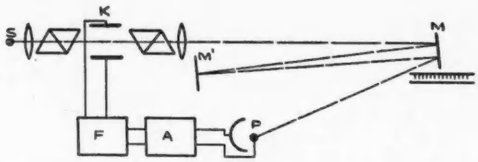

FIG. 5. Regenerative method applied to visible light.

An attempt is being made to apply the method to light with the arrangement shown in Fig. 5. Light from a source S is collimated and passed through a Kerr cell K and, after reflection from distant mirrors M and M', falls on a photoelectric cell P. This, in turn, acting through an amplifier A and band-pass filter F, controls the oscillations of the Kerr cell. The light is thus modulated by oscillations of the Kerr cell, the frequency of which will change through a repeating series of values as the mirror is moved continuously in the same direction. As before, the interval between successive settings to zero beat with a standard frequency gives the wave-length of the modulations and hence their speed of propagation. It is not necessary to measure the total length of the light path, and no measurement of intensity is in any way involved

A Falling Body Apparatus

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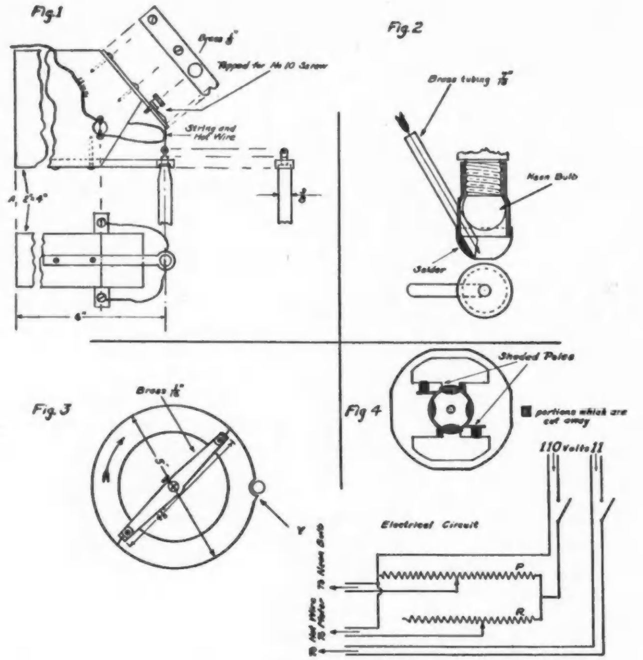
A FREE–FALL apparatus has been designed that is inexpensive and rugged, is easy to build and operate, and requires no special paper or timing apparatus for recording. Yet, it yields quite accurate results. Briefly, a small mixer motor (cost \$1) is made to run synchronously, and attached to the shaft is a crossarm to the ends of which are clamped short pig bristles. These bristles are inked and turn in a horizontal plane while a weighted aluminum rod around which ordinary adding machine paper has been clamped is allowed to fall past them. The bristles flick across the paper leaving lines which are spaced 1/60 sec in time. From the distances between these lines the acceleration due to gravity is determined in the usual manner.

The apparatus measures about 200 cm in height. The aluminum rod with the brass weight attached is 90 cm in length. The apparatus may be mounted on any kind of a tripod with provisions for leveling, or, if necessary, on a wall. We made use of an old falling-tuning-fork stand.

In Fig. 1, note that the guide for the upper end of the rod has a cross slot and the rod is filed to fit it; this is done to keep the rod from turning, since it hangs from a cord. The small upper end of the rod, which fits in the guide and has an eye for the string, is made of brass and is screwed into a tapped hole in the rod. The rod is released by throwing a switch in a low voltage line which heats a resistance wire and burns the string.

Figure 2 is an old-type key socket which has been rearranged. The paper insulation is left in place, and the key and socket are removed and merely inserted in the opposite end. A 1-w neon flash bulb is screwed in, and the cap to which a brass tube has been soldered is replaced (the key opening in the side of the socket body having been enlarged to accommodate the brass tube). The whole device is then clamped in such a

[1] This apparatus was developed while the author was at the University of Utah.



FIGS. 1–4. Detailed drawings of parts of apparatus. Note that 1 on the photograph (Fig. 5) and Fig. 1 refer to the same part.

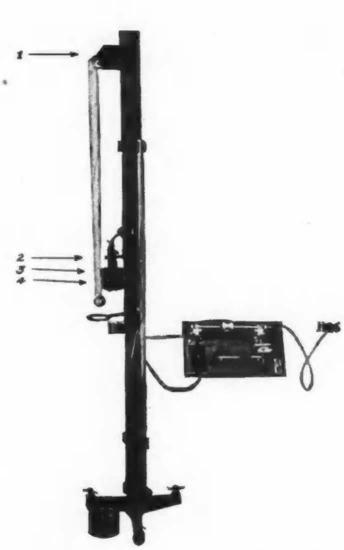


FIG. 5. Photograph of complete apparatus.

position that the hole in the cap covers the end of the motor shaft which has a cross filed in it, the cross being filled with black paint. If the neon lamp is connected to a potentiometer, the voltage can be regulated so that the lamp gives a short flash at the peak of the alternating wave. If, on looking down the tube, the cross appears to be at rest, the motor is then synchronizing at 1800 rev/min. This device thus allows one to synchronize the motor in full daylight.

Figure 3 represents the arm with the pig bristles on the ends and the device that inks them. The rotating arm is a piece of brass with a hole drilled in the center; it is soldered to a step on the bushing which originally was the means of attaching the beater to the mix-motor. The inking device, a coffee can lid with part of the center cut out, can be attached to the motor itself or held by a separate clamp or ring to the upright. A crescent is filed, or taken out, with an emery wheel so that the falling rod may take the position shown in the drawing and be flicked by the bristles as they revolve. Mimeograph ink is smeared in the corner of the lid. The bristles may be obtained from a shoe repair shop. The prepared end of each bristle is placed to the outside since it does not fray so easily. The other end is clamped in a groove under a washer which is held in place by a No. 8 screw in a tapped hole. The arms are bent down near the ends so as to give more clearance and, at the same time, to force the bristles to ride in the corner formed by the lid and the rim. The motor is set slightly eccentric with the lid, the bristles being of such a length as just to make contact with the rim at the side near the rod and be slightly bent at the opposite side. At *Y*, the rim of the lid is bent out so that the bristle does not strike the edge when turning (clockwise), thus greatly prolonging the life of the bristles. It is surprising how stiff the bristle may be without disturbing the straight fall of the rod.

Figure 4 shows the changes made in the field and armature of the shaded pole motor[2] which,

[2] The motor used is a product of the Vidrio Co., Chicago, Ill.

wound two-pole, had a speed of over 3000 rev/min when running without load. Although the four slots shown were roughed out with an emery wheel and finished with a file, a milling machine would do a better job. Fig. 4 indicates approximately how much it was found necessary to slot the armature. As an experiment, part of the field pole was cut off and the iron pole connectors removed, which seemed to make the adjustment less critical for synchronization. It has also been found that, if enough of the armature is removed to make the motor run synchronously without load, it will run under synchronization while working against the friction of the bristles on the lid. Thus, it seems more advisable to cut away less of the armature and use a series rheostat to help control the speed. In practice, the motor can be made to run above or below synchronous speed by varying a 100-ohm rheostat. The adjustment for synchronization is not critical, it being possible to change the resistance by as much as 20 ohms without having the motor fall out of step. The motor is bolted to a ring, the shaft of which is threaded and bolted to the 2×4-in. upright. Another ring is so placed that the falling rod passes through it and strikes in a can of sand on the floor, the ring then preventing the rod from falling over.

TABLE I. *A set of data and calculations.*

READING	S (cm)	1ST DIFF.	2ND DIFF.	ω_i	$w_i(S_{i+2}-2S_{i+1}+S_i)$
1	1.00	1.35	1.10	180	18.00*
2	2.35	2.45	1.07	432	30.24
3	4.80	3.52	1.07	672	47.04
4	8.32	4.59	1.10	840	84.00
5	12.91	5.69	1.11	930	99.00
6	18.60	6.80	1.10	840	84.00
7	25.40	7.90	1.08	672	53.76
8	33.30	8.98	1.08	432	34.56
9	42.28	10.06	1.10	180	18.00
10	52.34	11.16			
11	63.50				
			$\Sigma\omega_i=5148$		468.60

$T=1/30$ sec; $g=(1+469/5150)900=981.9$ cm/sec².

* The first significant figure in 1.10, etc., is omitted to save computational labor. From reference 3, $g=\Sigma[w_i(S_{i+2}-2S_{i+1}+S_i)]/T^2\Sigma\omega_i$,

where $\omega_i=\omega_{n-i-1}=i(i+1)(n-i-1)(n-i)$

and $\Sigma\omega_i=(n-2)(n-1)n(n+1)(n+2)/30.$

In operation, a piece of adding machine paper of the proper length is clipped around the rod. A piece of string is inserted through the eye in the upper end of the rod and tied. The rod end and string are then put through the hole in the guide, the string centered in the notch, and a turn taken about the thumb screw which is then tightened. The leveling screws are adjusted until the rod hangs *freely* in the position shown in Fig. 3. With the switch for the neon lamp and motor circuit closed, the rheostat R is adjusted until the motor is observed to be turning synchronously. When the rod has quit swinging, the low voltage switch is closed; the hot wire burns the string, and the rod falls. Finally, the switches are opened and the rod and marked paper removed.

The paper is taken from the rod and placed on a flat surface. If the observer faces a window, the black lines on the paper are mirrored by the varnished surface of the meter stick, thus making it very easy to estimate to tenths of a millimeter. The readings are always taken from the end of the mark where the bristle first strikes the paper. Alternate marks may be used for one set of data and those in between for another set. Thus, one has two complete sets of 10 to 12 readings, each made by one of the two bristles. To test consistency, the second differences are found, which usually average about 1.09 cm per 1/30 sec per 1/30 sec; this corresponds approximately to a value of $g=1.09\times900=981$ cm/sec.[2]

Table I contains a sample set of data and a complete least-squares treatment following the method of P. Rudnick.[3] This method is easy to carry out and, if not provable to a sophomore student, is at least very plausible, because it treats the second differences directly.

One student working two afternoons obtained the values 979.2, 979.2, 974.7, 977.4, 975.6, 978.4, 986.9, and 978.5 cm/sec², showing the speed with which results can be obtained as well as their general consistency.

[3] Am. Phys. Teacher 4, 217 (1936).

A Moseley Law X-Ray Tube for Atomic Physics Laboratories

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Department of Physics, University of Cincinnati, Cincinnati, Ohio

IT is generally agreed that the work of Moseley on the frequency of the characteristic x-ray lines of the elements stands as one of the classic experiments in what we may now regard as the dawn of atomic physics. It follows, therefore, that his work deserves a place in the atomic physics or electronics laboratory along with such experiments as the determination of the ratio of charge to mass of the electron and Millikan's determination of the charge of the electron.

The object of this paper is to describe the construction and operation of a multiple target, self-rectifying, gas, x-ray tube of such design that the data for the verification of Moseley's law can be obtained in as little time as one afternoon and evening. A tube of this type places the Moseley law experiment on an equal footing, as regards time required and accuracy of experimental results, with the various experiments usually given in an atomic physics laboratory. The design is sufficiently simple so that the tube can be constructed in any shop equipped with a lathe. Other necessary equipment is to be found in almost any physics laboratory.

Design of the tube. The tube is of the cold cathode type and is evacuated continuously. Construction details of the tube are shown in Fig. 1 which is almost self-explanatory. The dimensions given on the drawing are not at all critical and may be varied to suit the particular material available. Except for the porcelain insulator *E*, the construction is entirely of metal. Permanent joints are made vacuum tight by soldering; demountable or moving parts, by Picein or vacuum wax. Six targets, Cr, Fe, Co, Ni, Cu, Mo, are soldered to the face of a drum *G*. By rotating the drum, which is mechanically connected through the tapered joint *H* to the handle *L*, any one of the targets (or the brass drum itself which gives Cu and Zn radiations) can be subjected to the electron beam from the cathode *D*. The tapered joint is made vacuum tight with vacuum wax and turns very easily even when the tube is evacuated. The cathode, the target drum, and the body of the tube are each water cooled in a manner which is obvious from Fig. 1. Since the tube is pumped continuously and a rather critical pressure is required for self-rectification, two ports *R* and *Q* are provided; one is connected directly to the vacuum system and the other, through a leak, to a ballast tank. It is believed that the rectification of the tube is greatly facilitated by making the face of the target drum *G* flush with the surrounding portions of the brass block *I*. This presents an almost plain surface to the cathode. The radiation from the target in position *K* issues from a slit in the end of the tube *J*. Over

* Now with the Du Bois Soap Co., Cincinnati, Ohio.

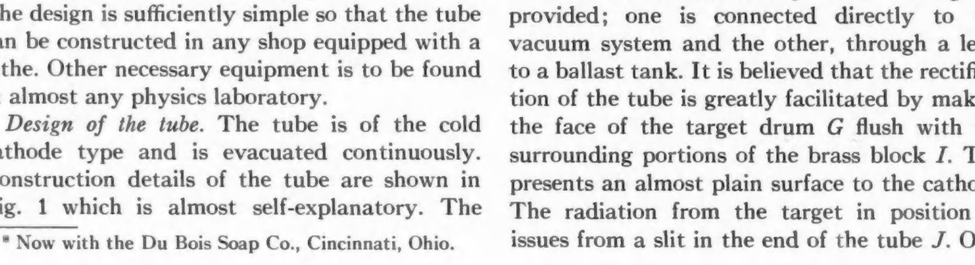

FIG. 1. Design of the x-ray tube. All cross-hatched parts are machined from brass. *A*, cathode end; *B*, anode end; *C*, cooling tubes; *D*, aluminum disk; *E*, porcelain insulator; *F*, brass collar; *G*, target holder; *H*, male end of joint; *I*, anode block; *J*, x-ray window; *K*, targets; *L*, handle; *M*, brass tube; *N*, cooling tubes; *O*, brass collar; *P*, collar; *Q*, port to leak; *R*, port to pump; *S*, water jacket; *T*, support tube. The tube is operated in the vertical position.

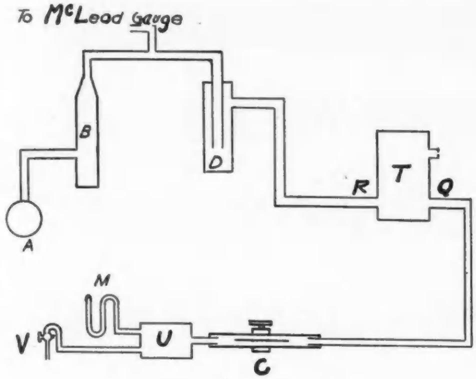

FIG. 2. Vacuum system.

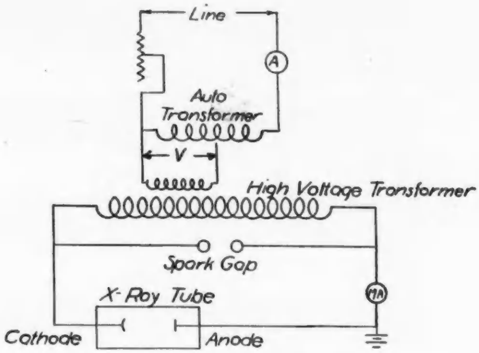

FIG. 3. Wiring diagram.

the slit is waxed a thin piece of Cellophane to make it vacuum tight.

The vacuum system. The x-ray tube T is evacuated by a one- or two-stage mercury vapor pump B backed by a Cenco Hyvac A (Fig. 2). The trap D and connecting tube from the mercury pump to the x-ray tube are made of iron water pipe and fittings, soldered at the threaded joints and painted over with shellac. A McLeod gauge is not really necessary, although convenient, particularly when the tube is first put into operation. The metal ballast tank U, of volume 0.5–1 l, is connected through a small rubber vacuum hose to the port Q. A No. 14 wire, about 2 in. long, is placed inside the rubber tube and a heavy tube clamp C clamped on the portion of the tube containing the wire. This forms a simple and effective leak. Almost perfect control of the flow of air from the ballast tank, which is kept at a pressure of about 1 cm of mercury by the glass valve V, can be maintained. At the beginning of operation the tube clamp is opened until the pressure in U, read by a small closed mercury manometer M, is reduced to about 1 cm.

The electrical system. In the electrical system (Fig. 3), any transformer giving a voltage up to about 50 kv can be used. It is best to supply the primary current for the transformer from a small auto-transformer. A ball spark gap is provided for determining approximately the high voltage applied to the tube. The anode of the tube is grounded. One terminal of the high voltage transformer is grounded through a d.c. milliammeter. Since the anode is grounded, it, as well as the body of the tube, can be cooled by connecting directly to the water mains. However, the water for cooling the cathode must be passed through a considerable length of small glass tubing to prevent a short circuit on the transformer. With a double length of about 16 ft of tubing, of inside diameter 2 mm, the leakage is very small; 4-ft lengths of the tubing can conveniently be mounted on a wooden frame and connected together with small rubber hose.

Operation of the tube. With the valve V (Fig. 2) closed and the leak C open, the Hyvac pump is started. When the pressure in the ballast tank reaches about 1 cm, the leak is closed. As soon as the pressure in the tube is about 100 microns, or less, the mercury pump is started. There is no necessity for cooling the trap. When the pressure has reached its lowest value, a voltage is applied to the primary of the transformer. If no discharge takes place, the leak should be opened slightly. A proper adjustment of the leak will then maintain a uniform rectified current. Some patience and time are generally required at the beginning in outgassing the tube. Outgassing is best accomplished by passing a rather heavy discharge through the tube with the leak closed. When outgassed the pressure will easily drop to such a point that the discharge will stop. It is then easy, by adjusting the leak and the auto-transformer, to get a rectified current of about 10 ma at any voltage up to 40–50 kv.

The camera. The very simple camera used for making the photographs of Fig. 4 consists of a

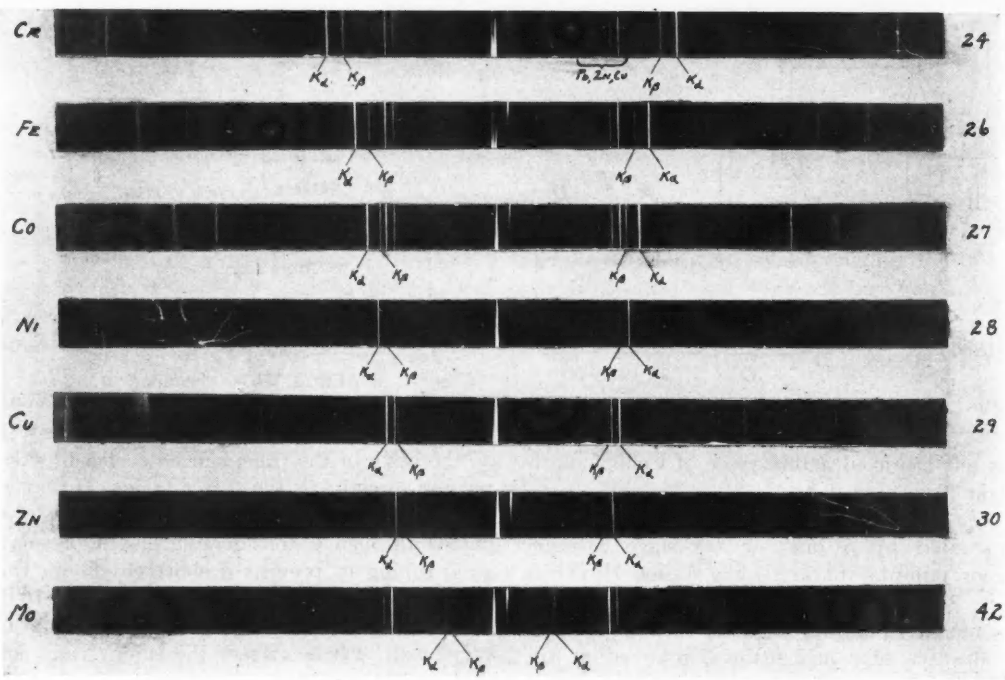

FIG. 4. X-ray spectra illustrating Moseley's law.

rotating rocksalt crystal mounted on the axis of a short brass cylinder of diameter about 8 cm, driven by an electric clock motor. A double-slit collimating tube is mounted on the circumference of the cylinder. A strip of film wrapped in black paper is held on the cylinder by means of rubber bands. The reflected radiation reaches the film through a wide slot cut around the circumference of the cylinder. Of course, any one of the many cameras described in the literature can be used.

Results. Experimental results are clearly demonstrated in Figs. 4 and 5, and Table I. These results are easily and quickly obtained, and are quite convincing to the student. No attempt at precision was made, although, with a carefully constructed camera, very precise results are possible. A few hours spent in verifying Moseley's law is sufficient to give the student real confidence in, and a feeling of actual contact with,

TABLE I. *Typical data obtained with an* NaCl *crystal. The distance from film to crystal was 3.8 cm.*

TARGET	DISTANCE TO MAIN BEAM (cm)	2θ	$\sin\theta$	WAVE-LENGTH (A)
Cr	3.2	48.2	.408	2.29
Fe	2.65	40.0	.342	1.92
Co	2.45	37.0	.317	1.78
Ni	2.25	33.8	.291	1.64
Cu	2.10	31.6	.272	1.53
Zn	2.00	30.1	.259	1.45
Mo	0.97	14.6	.127	0.71

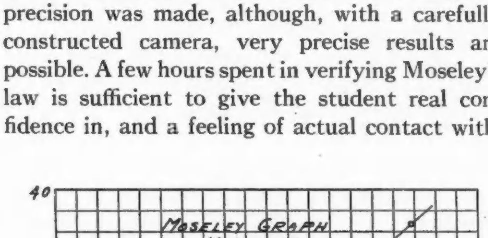

FIG. 5. Graph of experimental data.

this phase of the foundational work of atomic physics.

This tube is not only suitable for the purpose for which it was designed but, due to the intense beam of x-rays that can be obtained and the number of targets that are available by merely turning the handle, is also excellent for crystal analysis and research in biophysics. The authors will gladly communicate directly with anyone who may desire further details regarding its construction or operation.

Considerable credit for the success of this project is due to the skilful and willing assistance of Mr. William Lange in constructing the tube. The photographs of Fig. 4 were made by Mr. T. P. Long, now of Marietta College.

A Simplified and Compact Tricolor Mixing Device

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THE visual effect produced by two or more beams of light of different hue simultaneously received upon the same portion of the retina is of great importance in all fields of study in which color is involved. To the uninitiated this additive color effect upon the eye is not evident in everyday observations. Hence, especially devised demonstrations of the effect are desirable.

Numerous devices for demonstrating the effect of additively mixing colored lights have been described. Some are elaborate spectroscopic devices,[1] whereby both the intensities and the wavelengths of the various lights may be determined. Others are simpler and permit the addition of only two colors.[2] Demonstrating the additive mixture of three colors is of especial interest and value, however, because: (1) all known hues can be duplicated by the addition of three suitable colors (red, green, and blue) in various proportions, (2) the more prominent theories of color vision embody the idea of three sets of color receptors, and (3) most of the modern processes of color photography likewise make use of three component colors.

One of the most obvious ways of demonstrating the effect is to use three projection lanterns, the slide holder of each containing a card with a circular aperture and each of the latter being covered by a filter of different color. The lanterns are so placed that their circular fields of colored light (e.g. red, green, blue) mutually overlap on the screen as shown in Fig. 1. Although this method has satisfactory features, it is cumbersome and requires three projection lanterns. The scientific supply companies have on the market various forms of tricolor mixers which require only one light projector, or else contain their own light sources; but all such apparatus giving the familiar and desirable pattern shown in Fig. 1 are both expensive and bulky. The literature[3] also contains descriptions of various forms of color mixers designed to demonstrate the effect as shown in Fig. 1; these, too, are bulky or require numerous accessory pieces of apparatus.

Several other tricolor mixers producing other color patterns or only a single colored field have been described.[4] Those that depend upon shadows are cumbersome; those that utilize revolving disks or other revolving pieces are complex.[5]

[1] F. Allen, "New Tricolor Mixing Spectrometer," J. O. S. A. **8**, 339 (1924); C. E. Ferree and G. Rand, "Spectrum Color Mixer," J. Exp. Psych. **9**, 146–154 (1926).

[2] M. Luckiesh, *Color and Its Applications* (Van Nostrand, 1921), pp. 64–65; G. J. Hermann Kellner, "Color Mixing and Comparing Apparatus," J. O. S. A. and R. S. I. **7**, 77 (1923); J. Zeleny, "Color Mixers," Am. Phys. Teacher **4**, 100 (1936).

[3] J. J. Heilemann, "Lantern Slide Color Mixer," Am. Phys. Teacher **3**, 184 (1935); M. Luckiesh, "Demonstrating Color Mixture," J. O. S. A. and R. S. I. **7**, 658 (1923); E. R. Von Nardroff, "A New Apparatus for the Study of Color Phenomena," Phys. Rev. **3**, 304–309 (1896); A. T. Weinhold, *Physikalische Demonstrationen* (Barth, Leipzig, 1931), ed. 7, pp. 321–325.

[4] M. Luckiesh, "Demonstrating Color Mixture," J. O. S. A. and R. S. I. **7**, 657, 660 (1923); J. J. Heilemann, "Indicating Lantern Slide Color Mixer," Am. Phys. Teacher **4**, 211 (1936).

[5] F. L. Dimmick, "Accurate Differential Color Mixer," Am. J. Psych. **44**, 798 (1932); C. W. Keuffel, "Trichromatic Additive Colorimeter," J. O. S. A. **12**, 479 (1926); J. M. McGinnis and D. S. Piston, "Compact Color Mixer," J. O. S. A. **15**, 117 (1927); V. H. Pavlovic, "Color Mixing," Comptes rendus **204**, 1635–1636 (1937); V. H. Pavlovic, "Subjective Study of Color Mixtures," Comptes rendus **205**, 791–792 (1937); P. T. Young, "Differential Color Mixer With Stationary Discs," J. Exp. Psych. **6**, 323–343 (1923).

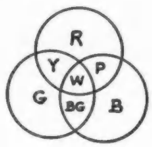

FIG. 1. Color pattern on screen. Symbols: R, red; Y, yellow; G, green; BG, blue-green; B, blue; P, purple; W, white.

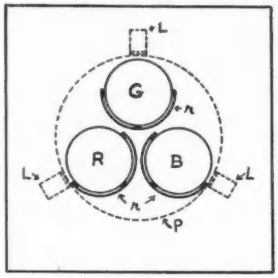

FIG. 2. Front view of assembly. Three thin metal lugs L, L, L hold the assembly over the front end of the projecting lens P. Instead of these lugs, a tapped, or drilled, block to receive a support rod may be added at the bottom edge.

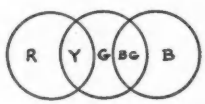

FIG. 3. This pattern and that of Fig. 1 are produced by the assembly of Fig. 2 with no prism over aperture G, a fixed prism over aperture B, and a rotatory prism over aperture R.

Newton's disks, and most of their modifications, are not truly additive, since the luminous intensity of the added colors is not additive, but simply an average value. The common motor-driven rotators are not capable of sufficient speed to eliminate flicker with Newton's disks.

General description of a new tricolor mixer.—For about a year the writer has been using a tricolor mixer of his own design which produces the familiar color pattern of Fig. 1. It is more compact than any other which has come to his attention, and it consists of only two small parts: (1) an opaque card, with a circular aperture which is to be placed in the slide holder of a projection lantern, and (2) a small, light-weight assembly which can be slipped over the projection lens of the lantern. This assembly (Fig. 2) consists of a brass plate (or plate of any rigid opaque substance) containing three apertures R, G, B all of the same size, but of any shape. The present one contains circular apertures spaced symmetrically. On the rear surface (not shown) of this brass plate are two retaining rims into each of which may be slipped a wedge-type, small-angle, prism to cover each of two apertures. On the front side of the brass plate are three semicircular rims r, r, r into each of which may be slipped a color filter to cover each of the three apertures.

To use this device, the single aperture card is placed in the slide holder of the projection lantern, the projection lens is adjusted to produce a sharply focused image of this circular aperture upon the projection screen, and then the assembly (Fig. 2) is either slipped over the projection lens or mounted close in front of it, on a tripod support rod. The addition of this assembly slightly dims the image, but does not otherwise alter it. By placing one of the three colored filters (red, green, or blue) over each of the three apertures the resulting image on the screen will be somewhat diminished in luminous intensity, but it will remain uniformly white if filters of suitable density and hue are used, and if the optical system of the projection lantern is in correct adjustment. (The projection lamp should be placed so that the image of its filament falls upon the filters.) Then a wedge-type prism is slipped into the rim over one of the apertures; the light through that aperture will be shifted to one side forming a second illuminated area on the screen. A second prism is slipped over a second aperture, similarly producing a shift in the second beam of light. By rotating one of these prisms about the beam of light as an axis, the three circular spots of light can be located symmetrically as shown in Fig. 1. Or, by further rotating one or both of the prisms, the spots of light can be shifted to some other position in which one of the composite hues and white may be omitted. In Fig. 3, for example, the purple and white are missing.

By partially or completely inserting over any aperture an opaque card, the intensity of the light through any aperture can be diminished at will. Or, if one prefers, the relative intensities may be altered by shifting the position of the assembly as suggested by Heilemann.[4] By partially or completely removing any color filter, any desired tint can be obtained. By rotating one of the prisms, movement may be introduced in the screen images. All of the usual additive color demonstrations can be conveniently shown with this device. The article by Von Nardroff[3] should be consulted for further suggestions.

The total cost of two prisms, three filters, and other incidental materials can be kept as low as two dollars approximately.[6]

[6] Bausch & Lomb markets crown glass, wedge-type prisms, 38 mm square, for various angular deviations, at reasonable prices. A corner of one must be ground off to

Demonstrating subtractive color mixing. The mixing of pigments is a subtractive process rather than the additive process dealt with in the foregoing discussion. All hues may be duplicated by mixing, in the correct proportions, three suitably chosen ideal pigments. It may be proved readily that these three subtractive primary pigment colors are the complements of the three additive primary colors. The new device can be used readily to demonstrate this fact in a beautiful and convincing manner, and at the same time it demonstrates the colors obtained by subtractive mixings. To do so, it is necessary only to replace the opaque card having a circular aperture by a clear lantern slide plate with a solid circle of opaque paper mounted at its center. If this opaque circle has the same diameter as the circular aperture in the card previously used, then the figure on the screen will be exactly like that of Fig. 1, except that the areas marked *R*, *G*, *B*, *Y*, *BG*, *P*, and *W* will be colored, respectively, *BG*, *P*, *Y*, *B*, *R*, *G*, and black. Each of the latter six colors is the complement of the corresponding former color, as may be verified by observing the pairs of colors on opposite sides of *W* in Fig. 1.

The subtractive primary colors are *BG*, *P*, and *Y*. These are the colors of the shadow circles because they are deficient in *R*, *G*, and *B*, respectively.

permit it to fit the assembly; the other may be ground round. Wratten filters, Nos. 29 (red), 61 (green), and 47 (blue), are excellent for the additive primary colors; but one may use the less expensive gelatine filters, such as those of the Display Stage Lighting Co., Nos. 65 (red), 48 (green), and 42 (blue). For demonstrations of complementary colors, one may use for *minus red*, *minus green*, and *minus blue*, respectively, Wratten filters, Nos. 44, 32, and 12, or Display Stage Lighting Co. filters, Nos. 44, 13, and 56.

Further suggestions concerning construction and manipulation. (1) To form the patterns shown in Figs. 1 and 3 within the usual screen area, the aperture in the slide should be not more than approximately one half the width of the slide opening; an aperture 1.5 in. in diameter is about right for the usual lantern.

(2) The three apertures in the assembly should be as large as possible, consistent with the size of the projection lens diameter.

(3) The refracting power required for the wedge-type prisms can be determined from the relationship, $\Delta=(100xd/f)(q-f)/q$, where Δ is the refracting power in prism diopters,[7] x the displacement, in diameters, of the circular image on the screen,[8] d the diameter of the aperture in the slide plate, f the focal length of the projection lens, and q the distance from the projection lens to the screen.

(4) With a little machine work, the filters and prisms can be mounted on pivoted arms to facilitate their manipulation.

(5) Having chosen prisms and constructed the apparatus, one may decrease the amount of overlap by decreasing q, the distance from the lantern to the projection screen.

[7] Prism diopters = 100 (tangent of angle of deviation).

[8] With regard to the values of x to be used to produce the pattern shown in Fig. 1: (*a*) If two prisms covering two apertures are used, x is the distance between any two centers of the circular images (Fig. 1) in terms of diameters of the circular images; for the amount of overlap in Fig. 1, x is about 0.6; (b) If three prisms covering three apertures are used, a smaller deviation is necessary for the same overlapping; x need have only $1/\sqrt{3}$ of the value needed in (a).

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Committee of the American Physical Society, *Physics in Relation to Medicine* (Reprint of 1923 report), 10 cts. per copy.

Dean E. Wooldridge, *The Separation of Isotopes—A Survey*, 60 cts. for 6 copies.

W. V. Houston, *The Physical Content of Quantum Mechanics*, 50 cts. for 6 copies.

Harvey L. Curtis, *The Principles Involved in Determining the Absolute Values of the Electrical Units*, 50 cts. for 6 copies.

R. Bowling Barnes and Lyman G. Bonner, *The Early History and the Methods of Infra-red Spectroscopy*, 60 cts. for 6 copies.

L. O. Grondahl, *Copper-Oxide Rectifiers and Their Applications*, 40 cts. for 6 copies.

L. W. Nordheim, *Present Conceptions of the Metallic State*, 30 cts. for 6 copies.

NOTES ON APPARATUS AND DEMONSTRATIONS

A Foolproof Geissler Tube Holder

DURING spectroscopic studies in the student laboratory it is often convenient to use a Geissler tube containing the gas under investigation. The tube and the wires connecting it to the high-voltage source are usually left exposed, a practice that is dangerous, especially if the experiment is carried out in a darkened room.

The Geissler tube holder which we have constructed in order to eliminate this danger consists essentially of a wooden box *A* (Fig. 1) containing a neon sign transformer with an output voltage of 2000–2500 v, and a turret box *B* with a glass window through which the Geissler tube may be viewed. The terminals *F* and *G*, which are in the primary circuit, are mounted on a piece of transite *H*. A piece of spring copper *K*, mounted on the lid of box *B*, completes the circuit between *F* and *G* only when the lid is closed and held by the latch *L*. Since the primary circuit is automatically broken whenever the box is opened to change the Geissler tubes, the possibility of the student touching any part of the apparatus which is at high voltage is eliminated.

A copper or brass spring is soldered to one of the secondary wires and bolted to a piece of transite, which in turn is screwed to the bottom of the box *B*. This spring is mounted inside a piece of Pyrex tubing large enough to admit the end *C* of the Geissler tube. The weight of the tube is sufficient to insure electrical contact at *C*. The other secondary wire is

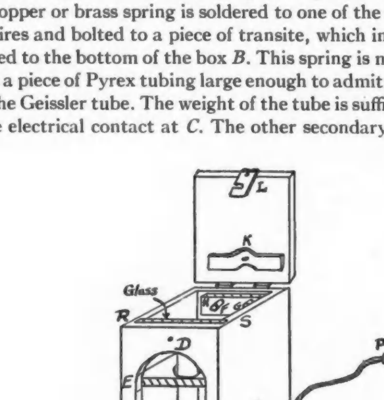

FIG. 1. Diagram of Geissler tube holder.

connected to the end *D* of the Geissler tube with a battery clip. The wooden partition *E*, which contains on opening large enough to admit the Geissler tube, serves to keep the top of the tube from wobbling. The glass window, which slips into the grooves *R* and *S*, makes it impossible for the operator to touch the apparatus either with his hands or with the collimator tube of the spectrometer.

We have used several of these tube holders with success in the elementary laboratory. Similar holders, but without the safety feature, have been used for several years at the Pennsylvania State College, and possibly other places.

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Simple Demonstrations of Auditory Perspective and Acoustic Regeneration

THE ability of a person to localize the source of sound in space is called *auditory perspective*. A very simple, yet effective, experiment will illustrate this principle. The speaker asks each person in his audience to place his hand flat over one ear, close his eyes, and point with the other hand to the speaker as the latter walks about the room. To make the experiment really "fair," the speaker should talk continuously. After he has walked for some distance, possibly retracing his steps, the speaker asks his listeners to open their eyes and note their inaccuracies in locating the source of sound. If the experiment is repeated with the listener using both ears, an increase in the accuracy of locating the source of sound will be noticed.

If a public address system is available, an interesting demonstration of standing waves may be performed. The reproducer (loudspeaker) is set up parallel to and about 10 to 15 ft from a wall, and the microphone is carried from place to place between the reproducer and the wall. A howl probably will be heard. This howl is sometimes called *acoustic regeneration* or, more commonly, "feed back." If the volume or gain control is turned up, it will be noticed that the pitch of the howl changes as the microphone is moved. The sound waves reflected from the wall interfere with those radiated directly from the reproducer, and standing waves are produced. In the standing wave pattern formed, a node will be found at the wall, and antinodes will be found at the reproducer and at the microphone. If the microphone is moved until sound of the same pitch is again heard, it will have been changed from one node to the next node; and the distance between the first and second positions will be equal to one-half wave-length. As the microphone is placed at various points, or as the distance between the reproducer and the wall is changed, several definite notes, each corresponding to a different wave pattern, will be heard. Thus, the possible standing wave

patterns determine the frequencies at which "feed back" will occur. If the microphone is left at a point such that a particularly loud note is emitted by the reproducer, a standing wave pattern throughout the whole room will be formed. This may be observed to advantage by covering one ear with the palm of the hand and moving about the room. The maximums and minimums of sound intensity will be very apparent. If the noise level of the room is low, it may be necessary to tap the microphone gently in order to furnish the impulse necessary to start the "feed back." When "feed back" occurs during the operation of public address systems, it may be eliminated sometimes by judicious placing of the microphone.

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Crystal Models Made on a Milling Machine

WHEN studying the structure of a crystal or when giving a classroom demonstration, it is desirable to have a model that is large enough to be handled conveniently. Such models have been made from both plaster of paris and paraffin with the aid of especially constructed apparatus. If a laboratory possesses a milling machine with a dividing head and a circular milling attachment, models of any crystal whose morphological angles are known may be constructed as easily as with a special machine. With the milling machine, models may be made of materials, such as wood or metal, that are more durable than paraffin or plaster of paris and with an accuracy approaching that of well-formed crystals.

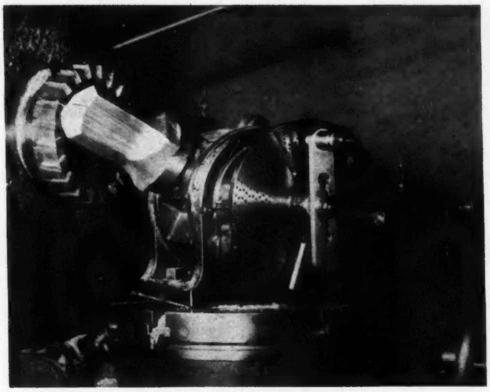

FIG. 1. Model of a crystal being made on a milling machine.

If the milling machine is large enough, models may be made from blocks of material 4 in. square by 6 in. long. The blocks are fastened to the face plate of the dividing head as shown in Fig. 1, and the prism faces cut with the plain milling cutter on an arbor. The remaining faces are best cut with the face mill, as illustrated in the figure. With this method of cutting, the original square end of a block forms a convenient base for the model. If one wishes a complete crystal, the two ends may be milled separately, their bases sawed off and the other ends glued together.

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H. KERSTEN

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Cincinnati, Ohio.

Appointment Service

REPRESENTATIVES of departments or of institutions having vacancies are urged to write to the Editor, Columbia University, for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned.*

20. Ph.D. Univ. of Minnesota; S.B., S.M., M.I.T.; 1 yr grad. work, Univ. of Iowa. Age 38, married, 2 children. 17 yrs teaching experience in universities, colleges and technical schools, including 10 yrs head of department. Interested in progressive undergraduate and graduate teaching and research, including mathematical physics.

21. M.S. Kansas State. Age 38, married, 2 children. Research, acoustics. Experienced in laboratory maintenance, design and construction of apparatus, and writing of manuals. Desires teaching or industrial laboratory employment.

22. Ph.D. Univ. of Illinois; A.B. Wabash College. Age 31, married, 2 children. Has taught 4 yrs in liberal arts college and 1 yr in large state university. Co-author, laboratory manual. Interested in college or university teaching, laboratory development, and research. Available, fall 1938.

23. M.S., B.S. Louisiana State Univ. Age 24, unmarried. 2 yrs teaching fellow, physics; 2 yrs practical engineering experience; 2 summers, seismic prospectings. Desires teaching or industrial laboratory position.

24. Ph.D. Age 32, married, no children. Experience: 4 yrs secondary school; 4 yrs instructor, state university; 3 yrs head of physics and mathematics, liberal arts college. Author, laboratory manual. Two research grants. Desires position in larger college or university.

25. Ph.D. Yale. Age 33, married, 2 children. Industrial research experience; 3 yrs instructor in small college. Interested in teaching in coeducational or mens liberal arts college. Available June 1938.

26. Ph.D., with long experience in an American college in China, wishes a college teaching position.

27. Ph.D., physics, Northwestern '35; A.B., engineering, Harvard. Age 42, married, 3 children. Experience: 1 yr, lt., artillery; 12 yrs business and sales; 5 yrs college teaching. Interested in undergraduate teaching, including astronomy.

28. B.S. in E.E., M.S., physics, Dr. Phil. Nat. from German univ. (Exchange fellow from U. S.) Age 32. 7 yrs teaching experience in advanced courses and physics for engineers.

29. Ph.D., Northwestern; M.S., Pittsburgh; A.B., Muskingum. Age 34, married, 1 child. Has had 13 yrs teaching experience in two universities. Interested in teaching and research.

Departments having vacancies or industrial concerns needing the services of a physicist are invited to publish announcements of their wants; there is no charge for this service.

Any member of the American Association of Physics Teachers may register for this Appointment Service and have a "Position Wanted" announcement published without charge.

DISCUSSION AND CORRESPONDENCE

Class Average?

ALMOST every teacher is asked if he grades by class average. Although it is sometimes necessary to grade that way, students should not be encouraged to accept the method as proper. The following has been found to call attention to the absurdities of "class average." A large number of students are assigned the same problem, preferably at the blackboard, and the answers are compared. If the problem requires two or three steps in the computation of a final answer, mistakes will be made. The question then is asked, "How are we to know the correct answer? By taking the class average?" Most students will see the point; but the question should be repeated at appropriate intervals.

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The Nature of Magnetism as Described in Elementary Textbooks

WHEN Weber[1] and Ewing[2] described magnetization in terms of oriented molecular magnets, they established a precedent which authors of modern elementary texts are reluctant to relinquish. For example, in the 1938 edition of one textbook we find the statement:

> "Since each atom has a magnetic field, the atoms are, in reality, miniature magnets. These miniature magnets are sometimes called magnetons. In unmagnetized material the axes of these miniature magnets are oriented in perfectly haphazard, higgledy-piggledy manner. . . . Under the influence of the magnetizing field they tend to rotate until their axes coincide with the lines of force of the field."

A statement of this kind is not in accord with modern ideas of ferromagnetism in solids. However, after checking through a representative list of 16 modern elementary textbooks of general physics, the writer found that eight of the texts stated that the atom or the molecule of the solid is the turning mechanism in the production of magnetization. Several authors are cautious enough to preface the explanation by such phrases as, "It is convenient to assume . . . ," or, "A possible explanation is . . . ." Five of the remaining texts examined use the term, "molecular magnets," without qualifying explanations, so that the student may easily infer that the molecule itself turns as a whole. Two of the texts gave explanations based on Ampère's theory of molecular currents.

The modern theory of magnetism does not postulate the turning of atoms or molecules as a whole. There may be slight reorientations of electron orbits in the case of paramagnetism; but in ferromagnetism it is the spinning electron, not the atom, which is the ultimate magnetic particle.

Of course it must be recognized that an elementary discussion cannot go very far into the theory of ferromagnetism, but it can at least keep somewhat up-to-date and avoid the confusions of the older theories. Given the old theory, a good student who knows something about the difference between molecular forces in solids and liquids will wonder how the molecules of a solid can be rotated through such large angles so easily. If he has had a crystal described to him, he will jump to the conclusion that in ferromagnetic crystals he can easily change the direction of the crystalline axis simply by changing the direction of magnetization of the crystal.

It is surprising that so many of the elementary texts go back to Weber for their paragraph on magnetism, when in some cases, at least, they devote considerable space to such topics as the space-time manifold of Minkowski, the equation for determining the wave-length of an electron, and the calculation of the mass of radiant energy.

C. W. HEAPS

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Houston, Texas.

[1] W. Weber, Ann. d. Physik **87**, 145 (1854).
[2] Ewing, *Magnetic Induction in Iron and Other Metals*, p. 287.

A Statement from a Special Committee of the Association

THE physics editor of the *Science Leaflet* has sought the good offices of the American Association of Physics Teachers in securing editorial aid. A special committee was appointed at the Indianapolis meeting to deal with the request. The Committee finds the request deserving of support and takes this means of bringing it to the attention of the membership.

The *Science Leaflet* is the organ of the Student Science Clubs of America. It differs from the usual scientific periodical in two respects. It is pitched carefully at the secondary school level, and it selects its subject matter to coincide with the subtopics which average secondary school classes are studying in the various sciences at the time of each weekly issue. In the words of one member of the committee, who was delegated to make careful inquiry on the ground: "All this is a labor of love, with no thought of reward except the reward of having filled a need. The editor-in-chief has never made a penny out of this work—instead, I am sure it has cost her quite a sum out of her own pocket."

The request is for volunteers to assume the responsibility for preparing the physics articles. The present physics editor, Dr. Andrew Longacre, of Phillips Exeter Academy, has been acting for two years. He suggests that the physics department of some college assume responsibility for all the issues of one year, after which the same responsibility will be transferred to another college.

This suggestion the Committee endorses and takes this method of making public. Doctor Longacre will be glad

to give any information that may be desired. A sample copy of the *Leaflet*, which in covering all the school sciences, averages 40 pages per issue, may be secured from the Committee. It is hoped that a number of individuals or departments will be interested in rendering this kind of service to the teaching of physics at the secondary school level. Any such person or group should communicate with the chairman of the Committee.

WHEELER P. DAVEY, Pennsylvania State College
RICHARD M. SUTTON, Haverford College
LLOYD W. TAYLOR, *Chairman*, Oberlin College

Letter Symbols for Physics

"$a_7c_5d_1e_5g_1h_1i_7l_4m_2n_9o_4p_2q_1r_2s_1t_5u_5$"

THUS Huygens wrote, in 1656, to announce his discovery that "Saturn is surrounded by a slender flat ring, nowhere adhering to it, and inclined to the ecliptic." The letters of the anagram, when rearranged, make the Latin version: "Saturnus cingitur annulo tenui, plano, nusquam coherente et ad eclipticam inclinato."[1] Many scientific discoveries of Huygens' day were couched in equally mysterious symbolism. While today there no longer persists this attitude of secretiveness in the physical sciences, we are often faced with the same problem of interpreting an author's meaning because he uses unfamiliar symbolism in equations.

For example, in three different books on atomic spectra, we find the symbol ν used in three senses: to denote (1) energy, (2) frequency, and (3) wave number. When we consult the three books on the same topic and read three equations of essentially equivalent meaning but different appearance, it is a matter of much loss of time to disentangle the confusion. For students, the net result is likely to be that they are never sure, in their memory, of any one of the three forms. Frequently an author falls into this error in different parts of the same book.

Another example, taken from a well-known book, is an equation for the magnetic interaction energy in the Zeeman effect,

$$\Delta W = Hg(e/2mc)mh/2\pi.$$

What is more natural than to cancel the two m's? Indeed, the author finds it necessary to explain in a footnote that the m in the numerator is the magnetic quantum number, and the m in the denominator is the mass of an electron.

A project to simplify the reading of equations as much as possible was initiated some years ago under the sponsorship of the American Association for the Advancement of Science, the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers, and the Society for the Promotion of Engineering Education. This is now known as "Sectional Committee Z 10 on Letter Symbols and Abbreviations for Use in Science and Engineering" of the American Standards Association. In January 1937, the American Association of Physics Teachers joined the project and appointed a committee jointly with the American Standards Association to study letter symbols for physics.

The committee has just completed a survey of current usage of letter symbols in physics and, before preparing a final report for presentation to the two Associations, desires to receive as many opinions as possible. The report has been mimeographed and a copy may be obtained by addressing a request to the chairman, Harold K. Hughes, Bard College, Columbia University, Annandale-on-Hudson, New York.

The committee takes this opportunity to acknowledge the benefit of opinions it has received up to the present time from: R. L. Allen, University of Western Ontario; Walter Barkas, Columbia University; Niel F. Beardsley, University of Chicago; Myron A. Coler, Paragon Paint Co.; H. W. Farwell, Columbia University; Edward C. Fuller, Bard College, Columbia University; John B. Hawkes, Stevens Institute of Technology; Harold Mestre, Bard College, Columbia University; J. Franklin Meyer, National Bureau of Standards; W. H. Michener, Carnegie Institute of Technology; Sanford A. Moss, General Electric Co.; George B. Pegram, Columbia University; R. E. Peterson, Westinghouse Electric and Manufacturing Co.; F. K. Richtmyer, Cornell University; Edward Ruestow, General Electric Co.; W. W. van Roosbroeck, Bell Telephone Laboratories; R. M. Sutton, Haverford College; Joseph Valasek, University of Minnesota; Le Roy D. Weld, Coe College; W. H. Williams, University of California; A. G. Worthing, University of Pittsburgh.

E. L. CHAFFEE	VICTOR F. LENZEN
A. W. FOSTER	MADELINE M. MITCHELL
GRANT O. GALE	DUANE ROLLER
A. T. JONES	HAROLD K. HUGHES, *Chairman*

[1] This is the statement of the original which J. C. Poggendorff gives on page 637 of his *Geschichte der Physik*. However, there are fewer letters in the anagram than in the solution. The two come into agreement by dropping the words "Saturnus" and "et" and changing the spelling of "coherente" to "cohaerente." Huygens published the anagram in 1656 and the solution three years later.

Maxwell's Treatment of Ohm's Law

A RECENT paper by Alexander[1] entitled "The Teaching of Ohm's Law" prompts the following remarks concerning Maxwell's treatment of this subject. Maxwell's statement of Ohm's law (Art. 241) reads: "The electromotive force acting between the extremities of any part of a circuit is the product of the strength of the current and the resistance of that part of the circuit." This is statement "E" of Ohm's law given by Alexander. In the same article, Maxwell states:

> "If by means of an electrometer we determine the electric potential at different points of a circuit in which a constant electric current is maintained, we shall find that in any portion of a circuit consisting of a single metal of uniform temperature throughout, the potential at any point exceeds that at any other point farther on in the direction of the current by a quantity depending on the strength of the current and on the nature and dimensions of the intervening portion of the circuit. The difference of the potentials at the extremities of this portion of the circuit is called the External electromotive force acting on it. If the portion of the circuit under consideration is not homogeneous, but contains transitions from one substance to another, from metals to electrolytes, or

from hotter to colder parts, there may be, besides the external electromotive force, Internal electromotive forces which must be taken into account.

"The relations between Electromotive Force, Current, and Resistance were first investigated by Dr. G. S. Ohm, in a work published in 1827 . . . ."

By electromotive force Maxwell meant the sum of the internal and external electromotive forces. Thus, in Article 280, "On Linear Systems of Conductors in General," Maxwell states:

"The most general case of a linear system is that of n points, $A_1, A_2, \cdots A_n$, connected together in pairs by $\frac{1}{2}n(n-1)$ linear conductors. Let the conductivity (or reciprocal of the resistance) of that conductor which connects any pair of points, say A_p and A_q, be called K_{pq}, and let the current from A_p to A_q be C_{pq}. Let P_p and P_q be the electric potentials at the point A_p and A_q respectively, and let the internal electromotive force, if there be any, along the conductor from A_p to A_q be E_{pq}.

"The current from A_p to A_q is, by Ohm's law,

$$C_{pq}=K_{pq}(P_p-P_q+E_{pq})."$$

This equation is essentially that given by Alexander [Eq. (1′) p. 70], $\epsilon_{ab}=\Sigma e-\Sigma RI$, though the latter is more general by virtue of the summation signs.

The words "internal" and "external" electromotive forces are no longer used in the sense suggested by Maxwell. External electromotive force is now called *a potential difference*, as Maxwell states, whereas internal electromotive force, such as is produced by a battery, etc., is now called simply *electromotive force*.

R. J. Stephenson

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[1] Am. Phys. Teacher **6**, 68 (1938).

Science and General Education

It is very gratifying to learn that the American Association for the Advancement of Science has decided to concern itself with the problem of science in general education. The Committee which the Association has appointed to inquire into the matter has a distinguished and widely representative membership which should give teachers of the sciences confidence in responding to its invitation for their cooperation. The program of work[1] is, moreover, one that will command the interest of all who are concerned with increasing the contribution of science to good citizenship.

It is impressive to a visitor to this country who has had the privilege of visiting a considerable number of schools and colleges to see how much teachers of all subjects are concerning themselves with the examination of the aims they are pursuing and with the effectiveness of the methods they are following. It is also very encouraging to see how good an insight into the multitudinous problems involved is being shown in the many experimental modifications in curriculums and in teaching procedures that are being tried out in various parts of the country. The experimental modifications in science teaching that are being tried in science departments show as great insight as any, though one gains the impression that those responsible for these modifications have been working under the disadvantage of having had but little opportunity for learning from each other's work. In view of this the American Association for the Advancement of Science should be congratulated on the initiative it has shown in setting up a committee which can serve as a very effective means of coordinating the experiments in progress and for helping in the development of further experiments.

The great interest in the remodeling of scientific education being shown in every part of the country is but one symptom of the growing recognition that the traditional ideal of "pure science" has prevented science teaching from making its full contribution to a liberal education and, through that, to the well-being of the community. In the past it has been too readily assumed by scientists that the results of their work must necessarily be of service to mankind and that they need not concern themselves with the ways their discoveries are applied in practice. Today, when there is increasing talk of technological unemployment, of production becoming unprofitable through the cheapness with which things can be manufactured, and when the expenditure on war research is mounting steadily, scientists are becoming increasingly uneasy about their earlier assumption. A clear sign of such uneasiness is shown by the foundation in England under the auspices of the Royal Society of an organization for the study of the social relations of science.[2]

The ideal of pure science has had the effect of encouraging people to make a sharp distinction between the study of the interactions of the various materials that fall within the province of the special sciences and the study of the interactions that take place between science and society. The effect of this has been to give the impression that scientific attitudes and methods are applicable only within the provinces of the special sciences, and not outside. This impression has been given further support by the fact that many men who have achieved eminence in particular sciences and who are scrupulous in their demands for evidence and for strict reasoning in their own work show little faith in either when they are concerned with social, political, or religious problems. Toward these problems their responses often are hardly different from those of people who have no scientific training at all.

It is true that in recent years increasing numbers of people have been seeking to make scientific studies of social questions. Unfortunately, most of these have approached their task with a literary, historical, or philosophical training which gives them very little sense of the methods of the inductive sciences. It is only a minority of workers who have made a truly scientific approach to the study of sociological questions. Their influence is, however, beginning to make itself felt in arousing the interest of scientists in the social consequences of the advance of science.

For science to be effective in general education[3]—as opposed to education aimed primarily at the training of specialists—it must give young people a sense of the applicability of scientific methods to problems of all kinds.

In the past, science teaching has tended to give people the impression that scientific knowledge is sharply distinct from all other kinds of knowledge and that what takes place in the laboratory is somehow quite different from anything that goes on outside it. It took this form for a number of reasons. One was that the demand for trained scientists in industry concentrated attention on the sciences that had the closest bearing on industry, especially physics and chemistry. A second was the anxiety that so many felt that scientific methods, if not confined to the subject matter of the natural sciences, would lead young people to challenge all accepted beliefs and so would undermine the foundations of religious faith and social stability. A third was the widespread belief in the disciplinary values of school subjects. This led to emphasis being put on the logical orderliness of the theories of the sciences, while little attention was paid to the methods whereby the sciences had been built up or to the social consequences of scientific discoveries. Yet another reason was that many teachers of science, trained according to the older methods, had but little sense of the general applicability of scientific methods.

The influences that went to make the science teaching of the past so very narrow in its outlook have today lost most of their force. *It is now open to teachers to devise a kind of science teaching that will be of greater value than anything which has yet been established in preparing young people to undertake the responsibilities of adult citizenship in a democratic society.* A number of points of especial importance are to be borne in mind in devising a program of science education that is to meet the needs of a democratic society. It must not only give young people a grounding in the principles of science, with the closest possible reference to practical affairs. It must also give them command of scientific methods and a clear sense of their general applicability to all questions of fact. It must, furthermore, give them an understanding of the enormous influence science has had on social development and the enormous benefits it has yet to confer on mankind if its results are applied to that end.

The especial contribution which physics has to make to young people's understanding of scientific method lies in the fact that it provides a means of showing them how the simplest forms of classification and the simplest causal relationships which form the basis of all science are recognized. It also provides magnificent opportunities for giving young people mastery of precise statement, and an understanding of how it is attained in the descriptions of things and events in which the problems of unambiguous statement are not great. It also provides occasion for making clear the process whereby more abstract terms are introduced to effect economies in thought and communication, and how the maintenance of precision of this kind is of crucial importance, not only in the development of other sciences where the objects studied are often less sharply distinct and the problems of precise statement are more difficult than in physics, but in all communication. These are but two of the contributions that physics teaching may make to general education, but they deserve special mention as far too little emphasis has been put on them in the past.

It is important not to underestimate the magnitude of the task that confronts the Committee appointed by the American Association for the Advancement of Science. Our conceptions of science have been given great rigidity by the traditions of the past, and they necessarily act as a considerable hindrance to our thinking through afresh the problem of science in education. It is for this reason that the Committee should have the benefit of suggestions from as many teachers of science as possible representing every level of education and every point of view.[4]

JOHN PILLEY

University of Bristol and
Columbia University.

[1] O. W. Caldwell, Science **87**, 454 (1938).
[2] Nature, Apr. 23 (1938); Science **87**, 463 (1938).
[3] See, also, the summary of an article by L. K. Frank in *Digest of Periodical Literature*, this issue.—EDITOR.
[4] The particular questions on which the Committee invites information are given by a member of the Committee, Professor Paul B. Sears, in Science **87**, 506 (1938). All who wish to contribute information should address the Chairman, Professor L. W. Taylor, Oberlin College, Oberlin, Ohio.

Electromotance

ONE of the most venerable misnomers in physics is "electromotive force." Textbooks have to explain that it is not force at all, and teachers have to repeat this several times. Students soon accept the situation, though sometimes with a query as to why there should be such an anomaly, and little misunderstanding results. That is one way to look at the matter. But, if we multiply the little trouble by the number that undergo it, we get a large total amount of unnecessary trouble. I believe some teachers try to escape the difficulty by avoiding the term itself and speaking only of e.m.f. or even emf. But there is still the telltale "f" to be explained, and the last estate of the artful dodger is apt to be worse than the first.

I suggest that what we are accustomed to call "electromotive force" be rechristened *electromotance*. It would be a new member of the large family of electrical terms ending in *-ance*. There is no objection to it that could not have been used against most of the others, and their success would insure its success. Our peculiar old friend e.m.f. will have served his day and passed on. We shall miss him, but younger teachers will not have to explain him, and the pathways of a multitude of students will be relieved of one small stumbling block.

If *electromotance* were adopted and became familiar, it would probably soon be shortened to "emotance." The reason for not proposing the adoption of emotance at once is that the direct transition to it from electromotive force would probably be regarded as very abrupt, and this might be an added cause of delay.

Textbooks could not introduce *electromotance* unless it is approved by some responsible organization. I believe most teachers would welcome it, but who is to take the initiative?

A. WILMER DUFF

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POSTVIEWS OF PHYSICS TEXTBOOKS

THESE reviews are innovations in that they represent the critical opinions of committees of teachers who have actually used the books as classroom texts. They are intended to provide specific ideas, suggestions, and constructive criticisms that will be helpful to teachers, authors, and publishers. The ultimate aim is to encourage the formulation of a body of sound opinion on physics textbooks, to the end that the science which can boast of incomparable methods and instruments of research may have a textbook literature of equally high quality.

If these reviews are to accomplish their purposes they must be frank and, when it seems necessary, severely critical. Yet, somewhat as in the evaluation of objects of art, many things that are said about textbooks must necessarily be matters of personal opinion. To please everybody with a text is, of course, impossible; there is too much about teaching and learning that is personal, and local, and artistic. Moreover, while criticizing textbooks in an effort to improve them, we should not be unmindful of the debts we owe to the authors of the books we have used. Once we have assimilated the good features of a book into our habits of teaching, it is natural to take these good features for granted and to remain aware only of the bad ones. Growing dissatisfaction with a textbook that once pleased us may mean, among other things, that we have milked the book dry so far as our own learning is concerned.—THE EDITOR.

An Advanced Course in General College Physics. PAUL LEVERNE BAYLEY, associate professor of physics, and CHARLES CLARENCE BIDWELL, professor of physics, Lehigh University. 355 p., 235 fig., 8 tables, 14×22 cm. *Macmillan*, $3.50.

Various college teachers have, from time to time, advocated the desirability of offering a second-year course that covers the field of general physics. They believe that such a course, with its necessary reviews, tends to remedy a half-learning situation existing in our present first-year courses, and that it makes possible the presentation of the analytic portions of general physics to those selected and interested students who can profit by it. Those who accept this point of view should welcome the book by Professors Bayley and Bidwell as a real addition to the textbook literature. The book endeavors to cover the entire field of general physics and includes an introduction to such advanced subjects as thermodynamics, electric circuit theory, and modern electron physics. The authors should be complimented upon the manner in which they have been able to include material from the whole general field in a single book. Perhaps this unification of the subject is the major point of merit. Intermediate textbooks on special fields whose presentation of the subject matter is equally good, or better, are available; but there is an advantage in having a single text for the intermediate general course.

The book attempts to bridge the gap between the descriptive first-year courses and the advanced courses which are specialized and more purely theoretical in character. It is, therefore, an intermediate rather than an advanced text, a fact that might well have been indicated in the title. Nor is the book of first-year grade, even for those beginners who have mathematical ability above the average. Indeed, one of us feels that the authors' endeavor to provide a book that could also be used with selected beginners has resulted to some extent in a text with too little descriptive material for a first-year course and too much elementary material for an intermediate course. This may be why it was necessary to slight such important subjects as alternating currents, flow of fluids, and damped and forced vibrations. On the whole, however, we feel that the authors have fulfilled the intentions which they outline in the Preface.

Calculus is introduced into the text gradually, and reasonably capable students are able to master the subject matter while taking beginning calculus. Thus the text aids in the transition from the elementary mathematics of first-year physics to the rigorous mathematical treatments of special fields.

In mechanics, the student is carefully guided through the calculus treatments of the fundamental kinematic and dynamical concepts; each step is based on the preceding material, and the developments here are made relatively complete. In heat, the treatment might well be cut in places, if the work of the second semester is to start with electricity, as it seems desirable for a course that is to be completed in one year.

The treatment of electricity and magnetism is generally commendable. The students, after their relatively thorough training in mechanics, easily grasp electrostatic and magnetic potentials; and the problems help them to appreciate the usefulness of these concepts. It was noticed that some students gain from the text the impression that electricity is somewhat more theoretical in character than the fields which precede it. Although the authors mention the recent agreements with regard to changes in the units of magnetic measurements, some of us regret that they chose to retain the older units in their treatment. It would also have been well, in an intermediate text, to have had specific sections and problems on alternating currents.

Light is introduced by a discussion of the electromagnetic spectrum. A discussion of reflection and refraction at a single spherical surface is conspicuously missing, although this topic is particularly appropriate for an intermediate course. A certain non-continuity of treatment seems to exist in light that is not found in the other excellently written divisions of the book.

A pleasing feature is the large number of suggested tasks, or problems, in the text proper; the student faces them right at the time when he is reading the textual

material, and thus is led to place proper emphasis on the important factors under discussion. As for the problems at the ends of the chapters, they are good, but those that are reasonably involved and require careful discrimination are too few in number for an intermediate text; often a mere substitution in a formula is all that is required. More practical applications of greater complexity and involving several principles would be desirable.

The literary composition of the book is excellent, and the language is chosen with regard for exact meanings. Student reaction is that each topic is quite concentrated and involves a few carefully worded statements without much descriptive material. There is missing to a certain degree, however, the satisfaction that follows the use of more extensive mathematical developments. For example, the description of Gauss' A and B positions is quite satisfactory, but there is no direct reference to the method to be employed for other positions, a question that immediately arises in the minds of many of the students.

The authors are to be congratulated for having produced a first edition that contains so few errors and misprints; although those that exist are mostly of minor importance, the authors have prepared a list of them which can be obtained on request. The book work is excellent; the diagrams are clear, and the printing easy to read.

Perhaps we have been overcritical with regard to certain omissions, for we believe that the book fills a real need in the field of second-year physics and we are glad to recommend it to our students.

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Everett F. Cox, *Colgate University*
Will V. Norris, *University of Oregon*

Sound. Floyd Rowe Watson, professor of experimental physics, University of Illinois. 219 p., 175 fig. and tables, 15×23 cm. *Wiley*, **$2.50.**

Acoustics is now a well-organized branch of classical physics, and the numerous and important accretions of the last two or three decades have done little to disturb the fundamental principles of the subject. These principles have been systematically and logically laid down in the standard works of Rayleigh and Helmholtz, names heading the list of references in Professor Watson's *Sound*. The authors of the classical treatises on sound made no concessions to the reader inadequately equipped with mathematical methods, and this rendered much simpler their task of formulating concisely and accurately the principles of the subject. Everyone knows how much more carefully a non-mathematical exposition of any part of physics must be developed; the long deductions and verbal explanations of results which are almost trivialities when expressed mathematically demand a special kind of courage and insight in the author of an elementary textbook. Some compromise must always be made between detailed accuracy and tedium, and the preservation of a judicious balance is all one can reasonably expect.

To give the student in any course a bird's-eye view of the subject at the beginning is desirable, and we therefore like the survey at the beginning of Professor Watson's book, even though it is very brief. The second chapter reviews simple harmonic motion, a topic that cannot be stressed too much in approaching a course on sound.

The descriptions of wave motion are relatively thorough, but somewhat tedious and labored. They are, however, good for students who lack mathematical preparation. The development of the equation for a progressive wave is awkward; the expressions for the displacements of various particles are written down and then generalized to represent the displacements of any particle. The occurrence of two independent variables, x and t, is not discussed, and only in a problem is the displacement equation written with the speed of the wave appearing explicitly.

One of us is using the book very successfully with a class composed mainly of freshmen who are majoring in music and who have had relatively little preparation in science and mathematics in secondary school. It is possible that the book is better adapted to the needs of such students than it is to those who plan to go on in physical science. The music students found that the discussions of consonance and dissonance of tones, and of tone quality, were condensed but adequate. More material on organ pipes, vibrating strings, the tone quality and tone structure of musical instruments might well be added for their purposes. The chapters on speech and hearing, and the acoustics of rooms, are excellent, and excited considerable interest. The music students found the last four chapters (Chaps. 17–20) too condensed and mathematical to be of much value.

For the student who is going on in physical science, there is a lack of precision and logical order in the text. Familiarity with some physical concept often is assumed at some point, but the definition of the concept does not come until later. Thus, resonance and the derivation of expressions for the speed of sound are not discussed until the closing chapters, although the results are used earlier. The only basis for the introduction of elasticity into a formula for the speed of sound on page 4 is the vague notion of strength of imaginary springs; and the important principle of superposition degenerates into statements like "two overlapping compressions create a louder sound" (p. 6). This procedure may be pedagogically desirable, but we doubt it. There is an advantage in mixing the more difficult parts with the easier, as they are needed.

Fourier's theorem (p. 123) is deprived of much of its significance. Among other things, it is not pointed out that the frequencies of the component tones are integral multiples of a fundamental frequency. The very abbreviated treatment of the Fourier analysis is, in our opinion, a major shortcoming of the book. Seldom do we encounter a sound wave that is simple harmonic, and it is the Fourier analysis that permits the transition from this ideal wave to the real one. Indeed, the Fourier analysis enters throughout acoustics; for example, a statement of the quality of a high fidelity radio has meaning only in terms of the harmonic composition of a sound.

In this text, and in others, one finds mention of "particles of air which vibrate;" and the student very naturally assumes that these "particles" are molecules. In Fig. 1*c*, "little portions of air" are indeed mentioned. Also, there are comments on the fact that the displacement amplitude

of a faint sound in air may be less than the diameter of a molecule; but there is no comparison with the mean free path of a molecule, which may be a thousand times greater. Students tend to think of molecules as rows of dominoes, one striking the other when the sound wave passes; Fig. 6*h* in fact shows a row of boys, hand on shoulder, pushing one another, as an analogy. The situation really is more like that of a swarm of bees which is gently oscillating and in which an individual bee may move many times the amplitude of swing of the swarm.

Some of the theorems and equations are intended to be taken on trust; an example is the expression for the ratio of the amplitudes of the incident and reflected waves for perpendicular incidence on a boundary between two gases, a formula which, as given, is valid only when γ is the same for both gases. To prove every theorem may not be necessary; yet it must be remembered that to assume a result is to break the logical sequence of development, and that this tends to make study degenerate into memorization of formulas. Some of the theorems stated without proof are indeed capable of simpler proof than others whose deductions are given.

The expressions for energy density and intensity are worked out; but, as is so often the case in texts, there is no discussion of the fact that the regions of greatest pressure are also those in which the speed of the particles of the medium is a maximum. Ordinarily we attribute to a volume of gas, potential energy equal to the work done in compressing it; and, from this point of view, the elements of volume that have the maximum kinetic energy also have the maximum potential energy. The author, however, considers the situation to be similar to that of a harmonic oscillator and states that when the kinetic energy is a maximum, the potential energy is a minimum. He avoids any discussion of the difficulty of localizing the potential energy. An obvious omission is the most useful of the expressions for sound intensity, that in terms of pressure changes. There is a slip in stating that the amplitude varies inversely as the square of the distance.

A treatment of combination tones is missing. The section on dissonance (p. 113) is weakened by the omission of fundamental experiments with tuning forks, where the "graph" showing discord as a function of frequency is not at all like Fig. 13*c*.

Laboratory work in sound in general physics is usually limited to two or three experiments; hence it is a distinct pleasure to find at the end of this book a very complete set of experiments which may be performed in the average laboratory. The experiments on reflection, refraction, and interference are especially useful in clarifying these topics in the minds of the students. The suggestions for making various types of acoustical apparatus are most welcome, and have been carried out by some of us with great success.

In an elementary work on any branch of physics, it should be the author's object to point out the interrelation of different phenomena rather than to develop, or merely state, a series of disconnected results, and to inculcate in the student the principles of logical deduction in accurate language. There is nothing to be lost, for instance, by emphasizing that the equivalence of a standing wave system to a mode of vibration of a string is simply a consequence of the fact that all waves travel along the string at the same speed. A general and quantitative definition of elasticity should precede any discussion of wave propagation; and that a book can be written on sound without any definite discussion of forced vibrations and resonance seems little short of miraculous. Although the efforts of many prominent teachers of physics have been directed to the eradication of certain evils in connection with the pedagogic methods of presenting curvilinear motion in mechanics, the author (p. 160) uses the "outward throw" of a string, a phrase to which no one could take greater exception than P. G. Tait, in connection with whose elegant proof of speed of waves in a string the words are used. There are in Watson's *Sound* many other instances where a slight formality would greatly enhance the value of the statements made.

C. Barnes, *University of Toronto*
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College Physics, John A. Eldridge, professor of physics, University of Iowa. 626 p., 407 fig., 52 tables, 13×21 cm. *Wiley*, $3.75.

One of Professor Eldridge's avowed objectives is to demonstrate that physics possesses great inherent interest and is a field for "inspiring adventure." For the student "who can take it," and who wants his fun and adventure to include intellectual activity, that purpose has been realized. An outstanding characteristic of the text is its ability to sustain enthusiasm for the study of physics; that it makes zestful reading is one point on which the better students have been unanimous. The poorer students, however, apparently find this book no more interesting than any other from which the physics itself has remained undeleted, and this despite the fact that the author's literary style makes for easy and pleasant reading. Although the book is intended for a beginner in the subject, the author expresses the hope that it will "impress the student with high school physics as in no means a mere redoing of his earlier work." This intention has been realized admirably, and without sacrificing the essential unity of the main offerings of the book.

For the amount of material included, the book is too brief; a hundred more pages might well have been used to tell the same story. Many books are altogether too verbose. This one is sometimes too terse, with the result that the explanations are not always well done; even the better students frequently miss the point when more detailed discussion might have saved the day. After all, a bit of repetition has its virtues and is far less damaging to the success of an explanation than too little repetition or too brief an initial discussion.

Some of us feel that the author sometimes has a disconcerting way of getting ahead of his story. Frequently he uses terms and presupposes knowledge from fields about which the student is uninformed and which are treated in later sections of the book. References to the later sections are sometimes given, but more often they are not. Some anticipation of subsequent material doubtless is inevitable and unavoidable, but in the present book there possibly is more than necessary.

The subject matter is built around fundamental principles rather than presented as a mass of loosely related phenomena. The sequence of material is mainly conventional, although the author is not at all enslaved by precedent, especially in the choice of topics. The first two chapters are entitled "Physics and Civilization" and "Physics and Common Knowledge." Since students often feel that physics is the strangest of all subjects, altogether too far removed from life as they know it, this kind of qualitative introduction is highly effective. The first chapter shows that physics is indeed a part of the world; and the second puts the student at ease by showing him that, after all, he already knows something about it—perhaps considerably more than he suspects.

In the chapters on mechanics, the treatments of constant acceleration and of vibratory motion are particularly attractive. The discussion of elasticity is rather difficult to follow; the form in which the coefficients of elasticity are given in the table confuses the students. Not all of us like the use of the British engineering system of units; though the system arises naturally from the engineer's primary interest in forces, one may question the use of the slug as the unit of mass, since apparently few engineers employ it in practice. In view of the many new topics treated in the book, it is almost inevitable, and is desirable, that a few useful old topics on mechanics, such as elastic and inelastic impact, be omitted altogether.

By discussing the various aspects of atomic and nuclear physics in their proper general divisions of electrostatics, current electricity, optics, etc., the author dispenses with the mystic aura with which some teachers have surrounded the term "modern physics." The chapter entitled "Magnetism of Iron" is really a survey of the magnetic properties of matter. The insertion of sections on radio tubes in the chapter on electrolysis is a violation of order that has little to recommend it. The use of conductance in deriving the law of parallel resistances (p. 367) may be questioned on pedagogic grounds, although it is used in many texts. More problems on electric circuits—batteries with internal resistance, various combinations of external resistance, etc.—would be highly desirable.

Some of us believe that Chapter 44, on parallel beams of light, contains too many different items; that Huygens' construction hardly belongs there and that the students find it confusing to encounter bits of the subjects of reflection and, especially, refraction there rather than in the chapters under those headings. On the other hand, one of us is of the opinion that this chapter, while unconventional, is one of the best in the book.

Aside from a few minor infractions, the book is remarkably free from errors of thought. The definitions, proofs of laws, and derivations of formulas are on the whole simple and clear, with no extraneous details. In only a few of the derivations—the treatments of viscosity and wave motion, for instance—are formulas set down without adequately justifying them. One typographical weakness exists which should be corrected in the new edition. The author starts out with the very commendable practice of placing words to be defined in bold face type, and general principles in italics. Before long, however, he uses any of three fonts with apparent indifference (pp. 128, 513, etc.), an inconsistency that led most of the students on one examination to state as Avogadro's hypothesis, that the molecules of common gases are composed of pairs of atoms (p. 55).

The book is profusely illustrated with diagrams and halftones which are often highly original and of unusual pedagogic value. Many textbooks have too few tables of constants; this has more than most and therefore succeeds in giving more concrete meaning to the subject. The index of the book is somewhat incomplete. Of the three appendixes, two are especially good, one giving advice on problem-working technic, and the other a mathematical review. In the latter, the trigonometric functions are tactfully introduced without the use of the word "trigonometry." This commendable practice of conveying ideas without frightening the student away with verbal paraphernalia is employed in various places in the text, but it is carried almost too far when the author introduces a gravitational and absolute system of mechanical units without any serious discussion of a consistent set of units.

Through the expedients of small type and starred sections, certain relatively ambitious items not usually found in an elementary text are treated. Some, like the discussions of trajectories as being elliptical instead of parabolic, are extensions of conventional subject matter; others are separate topics, such as Kepler's laws, special relativity, and electromagnetic theory, including modified verbal statements of Maxwell's equations. The author doubtless would agree that the latter sections will have fulfilled their mission if they give the student a desire to learn more, even though they may not themselves give more than an inkling of the subject. Although the starred sections may be omitted without damage, their inclusion greatly enriches the course for the more adventurous student who finds in them points of departure for interesting and worthwhile excursions into less familiar fields. This, together with persuasively suggested supplementary reading, often leads the student to the very frontiers of contemporary physics and gives a vivid appreciation of the fact that there is still "something doing" in the science. Well-selected biographical and historical material comprises important paragraphs in the book. Even the casual student is not likely to forget Newton's enlarged concept of the physical universe (p. 177), the versatility of Thomas Young (p. 565), or the state of physical science in America before 1900 (p. 246); or to fail to catch the importance of a knowledge of our energy resources (p. 219), or the role of physical law in biological processes (e.g., pp. 193, 261). The author has the apparently incurable habit of tempting the reader *to think*; he continually points out unsuspected implications and puts tantalizing questions, which, incidentally, he often does not answer—to the delight of those students who do not want to be told everything and who like to find at least some of the answers for themselves. The interesting, thought-provoking questions and problems at the end of each chapter actually do fulfill the author's expressed hope that they will "encourage physical thinking" and "the formulation of other questions by the student himself."

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DIGEST OF PERIODICAL LITERATURE

Apparatus and Demonstrations

A variable low resistance. W. H. Walton; *J. Sci. Inst.* **15**, 106, Mar., 1938. A mercury column, 30 cm long and 5 mm in diameter, enclosed in the stem and lower part of the bulb of a thistle funnel serves as a variable resistance of maximum value about 0.04 ohm. A terminal sealed into the end of the stem makes contact at the lower end of the column; a stout wire or strip of metal dips into the mercury in the bulb at the upper end. The resistance is varied by raising or lowering into the stem a 4-mm glass rod, held loosely in position by a cork in the funnel mouth. This rod reduces the mercury cross section to an annulus between it and the tube, thus increasing the resistance. —H. N. O.

Concrete bases for retort stands. O. H. F. Pieris; *J. Sci. Inst.* **13**, 417, Dec., 1936. Inexpensive, heavy bases for large retort stands and galvanometer lamp stands may be made from concrete. In comparison with cast metal, the only objection to concrete is the larger size required for a given weight. The mold may be made either of wood or galvanized iron. A brass tube, fitted at the top with a collar and screw to take the apparatus rod, passes vertically through the center of the concrete (Fig. 1). The tube has, soldered at its

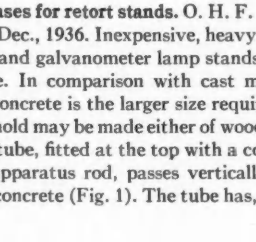

Fig. 1. Sectional elevation of concrete base.

middle, four strips of brass or iron to secure it in position. With the tube in position in the inverted mold, this is filled with a mixture of two parts of sand to one of concrete. The lower edge of the base may be strengthened with a strip of brass, or a turn of iron wire, inserted in the mold before casting.—H. N. O.

On the preparation of non-photographic lantern slides. D. R. Barber; *J. Sci. Inst.* **15**, 174, May, 1938. Diagrams for lecture demonstrations can be made on lantern slides prepared with a volatile solution of Canada balsam in benzole [H. A. Robinson, British J. Phot. **84**, 680 (1937)]. The writer has found this method very satisfactory but uses a solution of ¼ oz of Canada balsam in 2 oz of pure toluene. This solution will keep indefinitely in a well-stoppered bottle in a cool place. It may be applied to the clean, dry, lantern cover-glass by flowing a pool of the liquid from center to edge; or, by coating in one direction only with a soft camel-hair brush well charged with solution, complete coverage being insured by making a second application after the first has had time to dry thoroughly. After drying, which may be hastened by artificial heating, the thin transparent layer of balsam is ideal for lettering with an ordinary pen and waterproof ink. The slide is protected by binding it with a clear cover-glass. It will not crack or deteriorate in the projection lantern.—H. N. O.

What Is "General Education"?

The task of general education. L. K. Frank; *Soc. Frontier* **3**, 171–3, Mar., 1937. Since many of those engaged in educational work are almost openly resistant to proposals for the development of *general education*, there is need for some clarification of its aims and purposes, seen as arising from our recent cultural situation and its effect upon the growing individual; only thus can we begin to realize that the demand for such a program is more than a desire for modernizing subject matter and pedagogic methods.

Formal education has been dominated largely by ideals of scholarship and scientific endeavor which have been pushed down from graduate school into college, then secondary school, and then elementary school. Every step from the elementary school through to the university has been regarded as essentially a preparation for the next step. Emphasis has been upon mastery of subject matter and of skills, including the procedures known as scientific methods and the apparatus of scholarship. The imparting of knowledge that could be tested by examinations has naturally been a concomitant development. In consequence the changing interests and needs of the growing student have been deliberately sacrificed to an ever receding future competence toward which he was supposed to be approaching. There has been no consideration of how these various subject matters might be integrated. Indeed, the intent of most teachers has been to capture the student as a disciple for their particular fields and interests. The attempt of educational critics to question this process of training has, however, been regarded as an attack on scholarship and academic standards and a threat to the maintenance of sound educational procedures by those who are primarily committed to scientific or scholarly work and whose institutional position and personal security are bound up in the preservation of that program of training.

The general education of youth has heretofore been carried on by family, church, and community, through which agencies the young were introduced to the accepted ideas and beliefs, customs, and practices of our culture. But today those ideas and beliefs no longer exist in their earlier

clarity and strength; they have been confused, assailed, and in some instances destroyed, as have the sanctions behind them. Family, church, and neighborhood can no longer provide the older general education, nor would it be of value if they could, since we are in a changing climate of opinion involving a far-reaching shift in the conceptual and ideological framework of our lives. This shift is so all-embracing that few, if any, aspects of contemporary life can escape; and, because it involves the fundamentals of our thinking and values, it is of much greater significance than the more obvious social changes we so often discuss, such as urbanization, rapid transportation, communication, and the many other technologic alterations in our industrial and living conditions. These physical and technologic changes are modifying our habits of life and work, but they demand readjustments of minor significance as compared with the basic reorganizations necessitated by alteration in the climate of opinion arising from our scientific and artistic explorations. To understand both the need for and the major task of general education today, we must seek a clearer understanding of these changes in our basic ideas and conceptions, and realize how urgent is the need for illumination in the areas that are now so greatly confused.

In any culture, the basic conceptions of the whole framework of man's life are concerned with the nature of the universe, man's place therein, his relations to his society and to other individuals, and his conceptions of the self. The content and the sanctions of religion, of morals and ethics, and of government, as well as the fundamental character structure of a culture, are built upon these conceptions. At any one time in the history of a people there is a body of such ideas, beliefs, and meanings, shared by almost all members of that culture, with minor variations and divergencies. This is the climate of opinion in which the people live; they are immersed in, and subject to, it just as they are in a meteorologic climate of the geographic region, looking upon it as normal and inevitable until travel and reports teach otherwise. Throughout the world we find groups of people living under diverse cultures built upon the locally held conceptions and beliefs of their climate of opinion. Records of comparative culture and studies of comparative religion provide ample evidence of how divergent are these cultural organizations.

Our climate of opinion today is in a most confused and disorderly condition, for we are witnessing the cumulative disintegration of the basic ideas and conceptions upon which Western European culture has been built. The sciences, jointly and severally, have rendered untenable the cherished cosmology and time perspective of our inherited religion and have undermined the traditional ethical ideas of man's place in the universe and his destiny, with far-reaching consequences for the stability of our culture and for the character structure of our personalities. But this is only one aspect of our changing climate of opinion. Cultural anthropology has made us increasingly aware of our parochial conception of man's relations to this society and group life and has revealed many other forms of social and family relationships. Through these studies of other cultures, we see that the ideas and beliefs we have accepted for so long as the true and final statement of man's relation to his family and social group and therefore have cherished as the basis for our government and law, are, indeed, only one variety of many such ideas and beliefs and not necessarily the most humanely desirable. Thus we have sustained a terrific assault upon the fundamentals of our individual and group life from these cumulative scientific findings and theories. In themselves they are sufficient to account for much of the widespread and growing confusion we see everywhere in Western European cultures.

But the crumbling of these foundations of belief and of extra-human sanctions is only one part of the disintegration. The ideas of human nature and conduct that have long governed man's relation to other individuals, especially within the family, and have formed his conception of the self, are being replaced by new insights and beliefs provided by students of personality and mental hygiene. The ancient conviction of man's inborn wickedness and of the depravity of human nature that necessitated stern discipline and harsh punishment to make him more fit for society, is being challenged from many sides. The belief in human volition is undergoing extensive revision as intensive studies are revealing the coercive role of past experience in the individual's conduct and his naive unawareness of the needs, impulses, and desires that so largely impel him. These insights are providing an illumination of the persistent perplexities and aspirations in family relationships that is bringing far-reaching revisions in our traditional ideas and beliefs. The increasing knowledge of man's own body and its functioning has also rendered untenable the older ideas of a separate mind and a body, and by so much has shown the inadequacy of previous conceptions of man's behavior, disease, and organic needs.

If we reflect upon these far-reaching shifts in our climate of opinion, and what they signify for the immediate future of the individual and our society, we may begin to realize the nature of our educational task. The older conceptions were the products of the research and speculation of their time and as such were both valid and tenable. The Ptolemaic conception of the universe and the anthropocentric world were founded upon the best evidence and clearest thinking then available. The conceptions of man's relation to his society and his conception of the self were developed by long and arduous reflection, as we may plainly see in the Old Testament and in Greek speculations. It seems almost axiomatic, therefore, to say that the scientific work that has destroyed the older framework of ideas must provide the basic ideas and beliefs for the new

Thus, we come to the essential task of general education: the explicit formulation and inculcation of the emerging new ideas and conceptions, already implicit in our sciences and arts today, that are to dominate our future culture. This calls for an imaginative presentation, not of scientific facts or laws or methodologies, but of the larger meanings and significances of scientific research and of artistic insights. We must draw upon astronomy for an enlarged and more awesome picture of the scheme of things, with an immensely greater time perspective, for the past and for the future This newer conception of an enlarged universe must also be viewed in the light of the ideas now coming from modern physics and chemistry of relative, contingent, and ap-

proximate understandings, that are replacing the older absolutes and certainties about the nature and activities of existence. From geology, paleontology, and biology will come the newer ideas of our earth and of the slow process of evolution through which have emerged the various organisms including the latest arrival, man. The need is for coherent, interrelated conceptions of the nature of the universe and man's place therein, drawn from, and solidly supported by, scientific research, but presented so that they are meaningful and congruent. Today especially we can see the devastating influence of doubts and confusion over these cosmological and biological beliefs as man is striving to reach a new conception of his place in an evolving world, as a late comer upon the scene, with an immense mammalian heritage of animal capacities and functions that he need not be ashamed of nor attempt to ignore.

These altered views of man's place in the world must be accomplished by a revision, drawn from our growing scientific findings, of man's relation to his society and to other individuals, especially in the family, to provide a coherent basis for his conduct. The personality is so largely dominated by ideas and beliefs on this aspect of life that any uncertainty or conflict seriously imperils the stability of the individual's life. Moreover, the conception of the self that forms the matrix of personality is now distorted and obscured by the conflict of older ideas and beliefs with more recent conceptions, thereby creating an urgent need for general education to help clarify these vital concerns with the help of the newer insights and the newer meanings coming from scientific and artistic explorations.

General education also has the responsibility of deliberately interrupting the continuity of the cultural tradition in these vital areas of belief and feeling, so that the individual may be emancipated from loyalty to these ancient beliefs. We are beginning to accept the necessity of freeing individuals from the older cosmology and non-evolutionary biology, but we are either indifferent to, or timorous about, the acute need of emancipation from those ideas of human nature and conduct, surviving from most ancient times, that are destructive to most human values.—D. R.

RECENT PUBLICATIONS AND TEACHING AIDS

Textbooks for General Physics

Introduction to College Physics. Clinton Maury Kilby, professor of physics, Randolph-Macon Woman's College. Ed. 2. 407 p., 389 fig., 15 tables; 14×21 cm. *Van Nostrand*, $3.25. The present edition has been revised in the light of classroom experience with the text. The contents have been rearranged, and parts that the students found obscure have been rewritten and amplified. New illustrations, more illustrative examples and practical applications, and brief discussions of some recent advances have been added.

The Elements of Physics. Alpheus W. Smith, professor of physics, Ohio State University. Ed. 4. 809 p., 784 fig., 9 plates, 38 tables, 15×23 cm. *McGraw-Hill*, $3.75. In this revision, increased emphasis has been placed on the importance of physics in the other sciences and in the industries. Some important changes in the order of presentation have been made. Separate chapters on nuclear physics and on astrophysics have been introduced. Two new appendixes are devoted to definitions of important quantities and derivations involving calculus methods. There are many new illustrations.

Booklets and Catalogs

Curtis Lighting Publications. *Curtis Lighting* (1123 W. Jackson Blvd., Chicago), gratis. Two booklets, entitled *Eye Comfort* (Handbook *J*) and *When the Doors Swing Open*, containing many excellent photographs and diagrams of indirect lighting equipment and installations.

Dealer's Manual for Edison Batteries. 32 p., 21×27 cm, illustrated. *Thomas A. Edison, Inc.* (Emark Battery Div., Kearny, N. J.), gratis. A manual of technical information, service, sales, and advertising prepared for the use of service stations and dealers.

Hammer's Little Book. Ed. 12. 39 p., 14×20 cm. *Hammer Dry Plate & Film Co.* (Ohio Ave., and Miami St., St. Louis), gratis. Descriptions of Hammer plates and films, and useful information on exposure, developing, and similar photographic technics.

Celotex Publications. *Celotex Corporation* (919 N. Michigan Ave., Chicago), gratis. Two booklets:

Less Noise—Better Hearing. 58 p., 21×27 cm. Good discussions of noise quieting and acoustical correction, and descriptions of various Celotex acoustical products; excellent photographs and diagrams.

A Few Facts About Noise and Office Quieting. 7 p., 21×27 cm. Good diagrams.